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Implicit Memory Is Not Immune to Interference

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Does interference, a primary source of forgetting in explicit memory, also affect implicit memory? Several early and highly influential studies have suggested that implicit memory is immune to interference. In contrast, a number of subsequent investigations have reported evidence for interference. As well, amnesic patients, whose performance relies primarily on implicit memory, often show interference effects. A review of methods, materials, and findings suggests that interference occurs on implicit tests when targets and nontargets are similar and so compete as potential responses to the memory cue. Further, there is some evidence that the degree of interference on implicit tasks is affected by the number of competing items and their strength relative to the target. Interference effects in implicit memory seem to parallel those in explicit memory, and the authors consider the implications of this conclusion for theoretical concepts of memory and the brain.

The ability to retrieve a particular piece of information from memory can be impaired by learning additional information either before or after the critical target information. This phenomenon, termed *interference,* is a major source of forgetting on memory tests that require deliberate retrieval (i.e., *direct* or *explicit* tests; for reviews see M. C. Anderson & Neely, 1996; Crowder, 1976; Keppel, 1968; Postman & Underwood, 1973; Underwood, 1945). In contrast, memory tests that do not require deliberate retrieval (i.e., *indirect* or *implicit* tests; Graf & Schacter, 1985) are widely thought to be immune to interference (see reviews by M. C. Anderson & Neely, 1996; Hardcastle, 1993, 1996; Roediger & McDermott, 1993; Rovee-Collier, 1997; Schacter, Chiu, & Ochsner, 1993; Tulving & Schacter, 1990). Because of the key role that interference plays in producing forgetting on direct memory tests, the immunity of indirect tests represents a potentially important dissociation between the two. Along with other dissociations (e.g., differential effects of modality changes, levels of processing, or subject population; see Roediger & McDermott, 1993, for a review), these differences have been used to argue that direct and indirect tests measure different forms of memory and may even access different systems in the brain (e.g., Moscovitch, 1992, 1994; Schacter, 1998; Squire, 1992a, 1992b; Tulving & Schacter, 1990).

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In addition to representing a major dissociation between explicit and implicit memory, the immunity of implicit memory to the negative effects of prior and subsequent information constitutes an important boundary condition for the interference effects so pervasive in explicit memory. In this article we reexamine the evidence supporting the idea that implicit memory is immune to interference, consider evidence from more recent studies that also used implicit memory procedures but found contradictory results, and conclude that deliberate retrieval is not required for interference to occur. Instead, we suggest that for both deliberate and nondeliberate memory, interference occurs when nontarget items that are similar to the target compete with the target as potential responses to the retrieval cue. Further, the degree of interference is influenced by the number and strength of competing items. These conclusions, that interference acts in both explicit and implicit memory and is governed by the same factors in each, have important implications for theoretical constructs of memory and the brain, as is discussed in the article's final section.

Evidence For and Against Implicit Memory's Immunity to Interference

The conclusion that implicit memory is immune to interference rests largely on the results of several early and by now widely cited experiments. For example, Jacoby (1983, Experiment 4) found no evidence for interference on a word identification test in which participants attempted to read words that were flashed on the screen for such a short period of time that it was difficult to see them. Implicit memory for words presented earlier in the experiment was demonstrated by more accurate identification of those words compared with new words that were presented only at the test.

In Jacoby's (1983) experiment, participants first read a new list of 50 words each day for 5 consecutive days. For each day's list, 20 words were tested immediately after list presentation, 15 words were tested the next day, and 15 words were tested on the 5th and final day. Thus, with each passing day, there was an increased opportunity for items from previous lists to disrupt memory for the most recently presented list. Despite the increasing number of previous lists over the series of days, there was no evidence for proactive interference: The identification advantage for presented words over new words did not significantly decline as a function of the number of days (and thus lists) in the experiment on either the immediate or 24-hr delayed tests. Nor was there evidence for retroactive interference: For that part of each list tested on the 5th and final day, the advantage of presented words over new words did not decline as a function of the number of days (i.e., number of subsequently presented lists) between list presentation and this final test. Implicit memory was not affected by either proactive or retroactive interference in this experiment.

Consistent with this finding, Sloman, Hayman, Ohta, Law, and Tulving (1988) found that implicit memory tested by means of a word fragment completion test (e.g., an improved ability to complete the fragment _AR_VA__ after having studied AARDVARK) was not impaired by manipulations that typically lead to interference in explicit memory. For example, explicit memory is often reduced if another verbal task (e.g., studying more words) is interpolated between study and test of a critical list of words, compared with conditions in which the interpolated task is nonverbal. However, Sloman et al. (Experiment 5) found that the verbal or nonverbal nature of the interpolated task (studying more words vs. playing a video game) did not affect the rate at which fragments were completed with previously presented items. Likewise, on explicit tests, memory for later presented words is often worse than memory for earlier presented words because proactive interference from the earlier words hampers the retrieval of subsequent items. However, Sloman et al. (Experiment 6) found that fragment completion for words from different sections of a 100-word list did not change as a function of the number of previously presented words. On the basis of these results, Sloman et al. concluded that fragment completion was not affected by either retroactive (Experiment 5) or proactive (Experiment 6) interference.

Although the results of Jacoby (1983) and Sloman et al. (1988) strongly suggest that implicit memory is immune to interference, the most widely cited study in this regard is that of Graf and Schacter (1987).[1] They used a classic paired-associates task to directly compare the vulnerability of explicit and implicit memory to interference. Participants learned critical lists of stimulus–response word pairs (e.g., SHIRT–WINDOW). For some of these pairs, participants also learned additional lists in which the stimulus word was paired with other responses (e.g., SHIRT–ENERGY, SHIRT–FINGER, SHIRT–EDGE, etc.). At test, participants were given a word stem consisting of the first three letters of the critical response word (e.g., WIN-). This stem might be paired either with the original stimulus word (e.g., SHIRT–WIN-) or with a new stimulus word (e.g., BOTTLE–WIN-).

Participants in the explicit memory condition were told to complete each stem with a previously studied response word. Participants in the implicit memory condition were told to complete each stem "with the first word that came to mind"—no reference was made to the previously studied word pairs. Only participants tested in the explicit memory condition showed interference from having studied multiple response words; participants in the implicit memory condition did not. Participants in the implicit memory condition completed stems with critical response words at the same rate in the condition where additional response words had also been paired with the stimulus word as in the condition where the critical response word was the only response paired with the stimulus.

Taken together, these findings (Graf & Schacter, 1987; Jacoby, 1983; Sloman et al., 1988) appear to provide clear evidence that implicit memory is immune to interference. Across a variety of implicit memory procedures (word identification, fragment completion, or stem completion), retrieval of the target items was not affected by previously or subsequently learned information. These results for implicit memory tests stand in marked contrast to the rich literature on interference in explicit memory, where prior and subsequent learning typically disrupt retrieval of target items (M. C. Anderson & Neely, 1996; Crowder, 1976; Keppel, 1968; Postman & Underwood, 1973; Underwood, 1945). However, the picture regarding implicit memory's immunity to interference is complicated by the findings of other experiments that used similar indirect tests (word identification, fragment completion, free association) but obtained quite different results with respect to interference.

For example, although Jacoby (1983) did not find any evidence for proactive or retroactive interference on a word identification test, results from an experiment by Ratcliff and McKoon (1997, Experiment 2) suggest that at least some word identification tests can be affected by interference. Participants in this experiment were asked to study a target word (*died*), a similar word (*lied*), both words, or neither word. At test, the target word (*died*) was briefly flashed on the screen, followed by a mask. Participants were then presented with two alternatives (*died* or *lied*) and asked to indicate which had just appeared. Probability of a correct choice was highest (.87) when only the target word had been studied. If both the target and nontarget words had been studied, the probability of a correct choice was no better than if neither word had been studied (.78 in both cases). The probability of correctly identifying the target was lower still (.67) if only the nontarget word was studied. Ratcliff and McKoon did not formally test for proactive and retroactive interference (the nontarget alternatives occurred within the same list as the targets, and their position—preceding or succeeding the target—was not manipulated). Nonetheless, these results strongly suggest that studying a nontarget alternative can interfere with subsequent perceptual identification of a target word.

In the same way, although Sloman et al. (1988) did not find evidence for interference on their implicit word fragment completion test, a later study by Nelson, Keelean, and Negrao (1989) found equivalent interference on explicit and implicit word fragment tests. This experiment compared the word fragment completion performance of control participants who learned only a list of target words (e.g., HEEL) with that of participants who subsequently learned one of three additional nontarget lists. The non-

[1] For example, the Graf and Schacter (1987) paper has been cited on this topic by M. C. Anderson and Neely (1996), Hayman and Tulving (1989), Mori and Graf (1996), Moscovitch (1994), Reingold and Goshen-Gottstein (1996), Roediger and McDermott (1993), Rovee-Collier (1997), Schacter et al. (1993), Tulving and Schacter (1990), and Winocur, Moscovitch, and Bruni (1996), among others. Although Graf and Schacter largely restricted their original discussion to interference effects in explicit versus implicit memory for new associations, many of these later discussions interpreted it more widely as evidence for implicit memory's overall immunity to interference.

target list was composed of words perceptually similar to the target (e.g., PEEL), meaningfully related to the target (e.g., SHOE), or unrelated to the target in appearance or meaning (e.g., COARSE). At test, all participants were presented with word fragments that could be completed by words from the first, target list (e.g., _EEL). In the explicit condition, they were asked to complete each fragment with a word from the first study list. In the implicit condition, they were asked to complete each fragment with the first word that came to mind. The results were the same for both the explicit and implicit memory conditions: Participants in the perceptually related (PEEL) condition completed fewer fragments with target words than the other three groups, who did not differ. The size of the interference effect for perceptually related nontargets was the same regardless of whether participants were in the explicit or implicit condition.

The Nelson et al. (1989) experiment provides evidence for retroactive interference in fragment completion; a similar experiment by Lustig and Hasher (2001) provides evidence for proactive interference. Here, participants first saw nontarget items that had structures that were either similar (e.g., ANALOGY) or dissimilar (e.g., URGENCY) to target words (e.g., ALLERGY) that appeared in the second half of a presentation list. After completing several filler tasks, participants attempted to complete word fragments corresponding to the target items (e.g., A_L__GY for ALLERGY). Participants who had earlier been exposed to the similar nontargets (e.g., ANALOGY) completed fewer fragments and made more intrusions than did participants who had been exposed to the dissimilar nontargets (e.g., URGENCY). Contrary to the results of the Sloman et al. (1988) study, these two studies provide evidence that implicit fragment completion is vulnerable to both proactive (Lustig & Hasher, 2001) and retroactive (Nelson et al., 1989) interference.

Likewise, the results of an experiment by Winocur et al. (1996) contradict those of Graf and Schacter (1987), who found that explicit but not implicit memory for paired associates was affected by interference. In contrast, Winocur et al. reported that implicit memory for paired associates was more affected by interference than was explicit memory. In this study, participants first learned two lists of semantically related paired associates (e.g., List 1: BEE–HONEY; List 2: BEE–WASP). At test, participants were presented with the stimulus words (e.g., BEE–). Participants in the explicit condition were asked to respond with a word from the first list. Participants in the implicit condition were asked to respond with the first related word that came to mind. Participants in the explicit condition were more likely to produce a first-list word than were participants in the implicit condition, who produced an almost equal number of responses from the two lists. Thus, in a direct contradiction of previous work (e.g., Graf & Schacter, 1987; Jacoby, 1983; Sloman et al., 1988), the results of the Winocur et al. experiment suggest greater interference in implicit memory than in explicit memory.[2,3]

Data from amnesic patients provide further support for the idea that implicit memory is vulnerable to interference.[4] By definition, people with amnesia have severely impaired explicit memories, and their performance thus relies primarily on implicit memory. If explicit memory were required for interference and implicit memory were immune, people with amnesia would be less vulnerable than controls to the negative impact of interference on retrieval. Instead, amnesic patients are often more vulnerable than controls to interference (e.g., Kinsbourne & Winocur, 1980; Mayes, Pickering, & Fairbairn, 1987; Shimamura, Jurica, Mangels, Gershberg, & Knight, 1995; Warrington & Weiskrantz, 1978; Winocur et al., 1996; Winocur & Weiskrantz, 1976; but see Mayes & Downes, 1997). For example, when testing controls and people with left temporal lobe amnesia on a cued-recall version of their semantically related paired associates (List 1: BEE–HONEY; List 2: BEE–WASP) task, Winocur et al. found that the amnesic participants showed more evidence of vulnerability to proactive interference than did controls. The amnesic patients' sensitivity to interference relative to controls was evidenced both by their differentially poorer recall of List 2 as compared with List 1 and their higher rate of intrusions from the nontarget list (see also Mayes et al., 1987).

The Critical Difference? Similarity

Thus, although discussions of implicit memory tend to favor the interpretation that it is immune to interference, the experimental findings are mixed. Data from some studies (Graf & Schacter, 1987; Jacoby, 1983; Sloman et al., 1988) suggest that implicit memory is immune to interference, but data from other studies of non-brain-injured participants (Lustig & Hasher, 2001; Nelson et al., 1989; Ratcliff & McKoon, 1997; Winocur et al., 1996) and from studies of amnesic patients (e.g., Mayes et al., 1987; Winocur et al., 1996) contradict this conclusion. This seeming contradiction can be resolved by considering the factors that govern interference. In particular, similarity between target and nontarget items has a critical impact on interference regardless of the explicit or implicit nature of the test.

A well-established finding in the explicit memory literature is that nontarget items similar to the target items compete with the targets as potential responses to the memory cue, and response competition of this sort is a major mechanism of interference (e.g., Keppel, 1968; Melton & Irwin, 1940; Postman & Riley, 1959; Postman & Underwood, 1973; Underwood, 1945). Without some similarity between target and nontarget items, there may be no interference (Underwood, 1945). For example, the ability to remember a target list of paired adjectives after also studying an additional, nontarget list varies greatly depending on the nature of the nontarget list. If the nontarget list is also composed of paired

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[2] It should be noted that although the Winocur et al. (1996) results are highly suggestive regarding the presence of interference in implicit memory, the experiment lacks the control group used in more traditional interference designs (i.e., a group who either studied only the first list or whose second list consisted of dissimilar response words such as BEE–PENCIL).

[3] Winocur et al. (1996; see also Moscovitch, 1994) remarked on the contradiction between their results and those of Graf and Schacter (1987), suggesting that the discrepancy might have occurred because Graf and Schacter used word stem completion, a perceptual test, whereas they used related associations, a conceptual test. We suggest an alternative explanation, described later in this article.

[4] We are pointing out that amnesic patients' memory performance—thought to rely largely on implicit memory—is at least as influenced by interference as that of controls, not claiming that amnesic patients' memory problems are the result of an increased sensitivity to interference (see Mayes & Downes, 1997).

adjectives (i.e., is very similar to the target list), memory for the target list is greatly impaired. However, interference is greatly reduced if the nontarget list is composed of three-digit numbers (i.e., is very different from the target list); memory for the target list can be approximately as good as if no additional list had been studied (e.g., L. M. Johnson, 1933; McGeogh & McDonald, 1931; see also reviews by Crowder, 1976; Keppel, 1968; Underwood, 1945, 1957).

With the importance of similarity in mind, a close examination of the materials used in the investigations of interference in implicit memory reveals an interesting dichotomy: Those studies reporting evidence of interference in implicit memory (Lustig & Hasher, 2001; Nelson et al., 1989; Ratcliff & McKoon, 1997; Winocur et al., 1996) used nontarget items that were similar to the target items in a way that made the nontarget items potential (though incorrect) responses to the test cue (e.g., HEEL and PEEL for _EEL; HONEY and WASP for BEE–). In contrast, those studies that did not find evidence for interference (Graf & Schacter, 1987; Jacoby, 1983; Sloman et al., 1988) used nontarget items that were not similar to the targets. As a result, the nontargets used in the latter studies did not compete with the targets as potential responses to the cue (e.g., SHIRT, FINGER, ENERGY, etc. are unlikely to compete with WINDOW as a response to the word stem WIN– because they do not begin with those letters). Thus, the factor that determines interference is not whether the test measures explicit or implicit memory, but whether the target and nontarget items are similar to each other in a way that allows nontargets to compete with the target as a potential response.

Additional evidence for the importance of similarity as a prerequisite for competition comes from experiments that have examined facilitation and impairment on procedures commonly used to test implicit memory. For example, Ratcliff and McKoon (1997, Experiment 1; see also Ratcliff, McKoon, & Verwoerd, 1989) found that identification of a briefly presented word (e.g., *died*) was impaired by prior study of a similar word (e.g., *lied*), compared with prior study of either an unrelated word (e.g., *sofa*) or the target itself (e.g., *died*). The same pattern has been found for word fragment tests: The ability to complete a word fragment (e.g., A_L__GY with ALLERGY) is impaired by prior study of a similar but incorrect word (e.g., ANALOGY), compared with prior study of either an unrelated word (e.g., UNICORN) or the correct completion (e.g., ALLERGY; Smith & Tindell, 1997). Thus, on both of these procedures, prior study of a similar but incorrect response impaired participants' ability to produce the target response compared with studying either an unrelated incorrect response or the target.

The data regarding amnesic patients' vulnerability to interference is also consistent with the idea that similarity is a critical factor for interference in implicit memory (e.g., Winocur & Weiskrantz, 1976). For example, amnesic patients' ability to recall a critical list of semantically related paired associates (e.g., CHAIR–BENCH) is greatly impaired compared with controls' if the nontarget responses also share a semantic relationship to the stimulus word (e.g., CHAIR–TABLE). However, amnesic patients are no more affected by interference than controls if the nontarget responses are unrelated to the stimulus word (e.g., CHAIR–BUTTON) or are related to the stimulus word on the basis of rhyme rather than meaning (e.g., CHAIR–PAIR).

Thus, the idea that interference depends not on deliberate retrieval but instead on the similarity of target and nontarget responses receives support from several areas of research. First, for those experiments that directly address the question of interference in implicit memory, interference is not found when targets and nontargets are dissimilar (Graf & Schacter, 1987; Jacoby, 1983; Sloman et al., 1988). However, implicit memory is at least as vulnerable as explicit memory when targets and nontargets are similar (Lustig & Hasher, 2001; Nelson et al., 1989; Ratcliff & McKoon, 1997; Winocur et al., 1996). Second, on procedures often used as implicit tests (e.g., word identification, fragment completion), prior study of an incorrect word similar to a never-studied target response can impair the ability to produce the target response on a later test (e.g., Ratcliff & McKoon, 1997; Smith & Tindell, 1997). Finally, amnesic patients, whose performance relies primarily on implicit memory, are not immune to interference. Instead, people with amnesia may be even more vulnerable to interference than controls when the target and nontarget responses are very similar (e.g., Winocur & Weiskrantz, 1976).

A potential argument against the idea that interference depends on similarity rather than deliberate retrieval rests on the observation that most earlier investigations did not closely control for the possibility that participants may have engaged in deliberate retrieval despite being tested with nondeliberate memory instructions. By this argument, findings of interference on nominally implicit tests are actually the result of "contamination" from explicit memory. However, there are several reasons to discount this alternative explanation.

First, the potential for explicit contamination is equal for those earlier studies that both showed (Nelson et al., 1989; Ratcliff & McKoon, 1997; Winocur et al., 1996) and did not show (Graf & Schacter, 1987; Jacoby, 1983; Sloman et al., 1988) evidence for interference in implicit memory. The distinguishing characteristic between these studies is thus target–nontarget similarity, not opportunity for contamination. Second, a more recent study (Lustig & Hasher, 2001) that took several measures to avoid contamination (e.g., excluding data from participants who noticed a connection between the implicit test and earlier study using incidental learning and very fast presentation rates; see Roediger & McDermott, 1993) nonetheless showed strong evidence for interference. Third, in procedures often used as tests of implicit memory, participants show interference-like effects even when instructed to actively avoid retrieving the nontarget item (e.g., Logan & Balota, 2000; Smith & Tindell, 1997; see also Jacoby, 1991, and related work). Fourth, if interference depended on explicit memory, amnesic patients' reduced explicit memories should be associated with less, not more, interference compared with control participants' intact explicit memory function, but the opposite is true. Likewise, Winocur et al. found that when target–nontarget similarity was high, participants that were tested under explicit memory instructions showed less interference than did those that were tested under implicit memory instructions. Taken together, the bulk of the evidence weighs heavily against the idea that interference on implicit memory tests is simply the result of explicit contamination. Instead, interference on both implicit and explicit tests seems to depend critically on target–nontarget similarity.

It is important to note that the similarity between the target and nontarget responses *must be on a basis important for responding to the test cue* for interference to occur. This qualification is clearly illustrated by the results of Nelson et al. (1989, Experiment 1). Interference on a word fragment test (e.g., _EEL) occurred when the nontarget item (e.g., PEEL) was similar to the target word (e.g., HEEL) in a way that made the nontarget a potential response to the fragment. However, no interference occurred when the nontarget item (e.g., SHOE) was similar in meaning to the target but could not complete the fragment. Further, the ability to complete a word fragment (e.g., S_UNK) with the target word (e.g., SKUNK) is no more affected by interference from a nontarget (e.g., STUNK) similar in both structure and meaning than from a nontarget (e.g., SPUNK) similar on the basis of structure alone (Nelson et al., 1989, Experiment 3).

We suggest that this critical requirement for interference—that the similarity between the target and nontarget be on a basis important for responding to the test cue—can explain why Graf and Schacter (1987) found interference on an explicit test but not on an implicit test. For both the implicit and explicit tests, participants were presented with the same nominal cue, a stimulus word and a word stem (e.g., SHIRT–WIN–). However, the memory cue was functionally different for the explicit test than for the implicit test. In the explicit test participants had to retrieve a response word from one of the studied pairs. The target and nontarget items were similar in that both were studied response words. The instruction to retrieve a response word may thus have brought to mind both target and nontarget response words (e.g., FINGER, WINDOW, EDGE, ENERGY, and so forth), leading to interference on the explicit test.

In contrast, the implicit test used by Graf and Schacter (1987) only required participants to produce a word that completed the stem; there was no reference to the previously studied stimulus–response pairs. As a result, the similarity between target and nontarget responses on the dimension of being studied response words was not relevant for the implicit test. Instead, the relevant aspect of the memory cue was the word stem (e.g., WIN-). Because no other words in the experiment began with the same three letters as the target word, they did not compete with the target as possible responses to the stem. As a result, there was no evidence for interference on the implicit test.

The opposite situation holds in the case of Winocur et al. (1996), who found evidence for more interference on their implicit test than on their explicit test. This finding, which is in direct contradiction to that of Graf and Schacter (1987) when the two studies are viewed from an explicit–implicit perspective, is consistent with that of Graf and Schacter from the perspective offered here: that interference is determined by similarity on a test-relevant basis. For the Winocur et al. experiment, the target and nontarget responses (List 1: HONEY; List 2: WASP) were similar in that both had meanings related to the stimulus word (BEE) and different in list membership (List 1 or List 2). For the implicit test, the difference in list membership was irrelevant—participants were simply instructed to produce the first related word that came to mind in response to the stimulus word (e.g., BEE–). Because both the target and the nontarget words were meaningfully related to the stimulus word and very similar in that regard, interference was high. For the explicit test, list membership differentiated the target response from the nontarget response—participants were instructed to retrieve the appropriate response word from the first list in response to the stimulus word. Because the target and nontarget words were not similar in list membership, interference was reduced on the explicit test compared with the implicit test.

In summary, not only is interference possible in implicit memory, but a reading of the full literature suggests that interference in explicit and implicit memory is determined by a common factor: similarity between target and nontarget responses on a basis important for responding to the memory cue. On tests of explicit memory, the amount of interference is also influenced by at least two additional factors: the number of nontarget items that compete with the target and the relative strength of the target to the competing items (see, e.g., Keppel, 1968; Keppel & Underwood, 1962; McGeogh, 1942; Melton & Irwin, 1940; Postman & Riley, 1959; Underwood, 1945, 1957). The next section examines whether these two factors may also affect interference in implicit memory.

Modifying Factors: Number and Strength of Competing Items

On tests of explicit memory, the number of competitors helps determine the degree of interference. In general, as the number of potential candidates for response increases, the efficiency (speed and accuracy) of retrieving the target response decreases. This phenomenon is often studied in the context of *fan effects* (J. R. Anderson, 1974, 1976), *cue overload effects* (e.g., Watkins & Watkins, 1975), or *set size effects* (e.g., Nelson, McKinney, Gee, & Janczura, 1998; Nelson, Schreiber, & McEvoy, 1992). The term *fan effect* refers to the finding that it is difficult to retrieve a particular piece of information in response to a cue when many other items are also associated with (fan off or overload) that cue. *Set size* refers to the number of items related to a word along a particular dimension such as meaning or spelling. For example, a word's meaning set size refers to the number of words meaningfully related to it. In general, words with small set sizes are better retrieval cues for the other words in their set than are words with large set sizes (see Nelson et al., 1992, 1998). If interference occurs under the same circumstances in both explicit and implicit memory, implicit memory will also be influenced by the number of responses competing with the target.

Several findings suggest that implicit memory, like explicit memory, is affected by the number of nontarget responses competing with the target. For example, tests that rely on structural information, such as word fragment completion, are influenced by lexical set size, or the number of words that can complete the fragment (Nelson, Canas, Bajo, & Keelean, 1987; Nelson et al., 1989; Nelson, McEvoy, & Bajo, 1984, 1988). The larger the lexical set size, the less likely it is that the fragment will be completed by the target word. Likewise, tests that rely on meaning-based information, such as word association (e.g., study SILVER, later produce the first word that comes to mind in response to the cue word GOLD), are influenced by the meaning set size of both the target word and the cue word. The more words that have meanings related to that of the target word (e.g., SILVER) or the cue word (e.g., GOLD), the less likely it is that the target word will be produced as a response to the cue. These set size effects occur regardless of whether the test uses explicit or implicit instructions (e.g., McEvoy, Holley, & Nelson, 1995). For both explicit and implicit memory, larger set sizes lead to greater competition because larger numbers of competing items reduce the probability that the cue will be completed with a studied word.

Further evidence that the number of potential responses influences retrieval on indirect tests comes from the letter insertion and letter deletion tasks introduced by Reingold (1995, Experiment 1). For the letter insertion task, participants first read a series of five-letter words (e.g., ARENA). At test, these participants were presented with four-letter words (e.g., AREA) and two letters (e.g., N, P) or four-letter nonwords (e.g., AENA) and two letters (e.g., R, P). Participants were told to select the letter that would create a word when inserted into the test stimulus. In the letter deletion task, participants first read a series of four-letter words (e.g., AREA). At test, participants were given five-letter words or nonwords with two letters underlined (e.g., ARENA or AREPA) and asked to select the letter whose deletion would result in a word.

The letter insertion procedure had many possible candidates for response because there were many possible places where either of the two letter choices could be inserted, and participants had to search through these possibilities to find the correct one. In contrast, the letter deletion procedure had only two possible candidates for response (either of the underlined letters). Thus, competition among responses (and thus interference) would have been greater on the letter insertion procedure than on the letter deletion procedure. This was indeed the case.

For both the letter insertion and the letter deletion tests, the critical comparison in terms of interference effects is between the word and nonword test cues. Word cues cause interference in comparison with nonword cues because the presence of a similar, nontarget word leads to competition with production of the target word. For both the letter insertion and letter deletion tasks, the word cues led to interference: Word cues were solved more slowly than were nonword cues. However, the response time difference between word and nonword cues was greater for the letter insertion task than for the letter deletion task, as would be expected if a greater number of potential responses leads to greater interference.

The results of studies by Nelson and colleagues (Nelson et al., 1987, 1989; McEvoy et al., 1995) and Reingold (1995) thus clearly show that the number of possible responses to the test cue affects implicit memory. The greater the number of potential responses that can compete with the target, the less likely it is that the cue will be completed by the target item. These results are comparable with competition effects reported in the fan, set size, and cue overload literatures that use explicit memory tests (e.g., J. R. Anderson, 1974, 1976; Nelson et al., 1992, 1998; Watkins & Watkins, 1975).

The memory performance of amnesic patients is also sensitive to the number of potential responses to the memory cue. Warrington and Weiskrantz (1974, Experiment 2) compared amnesic and control participants' stem-cued recall of a list of studied words when the stems could only be completed by a few (4–6) words in the English language versus when the stems could be completed by many (10 or more) words in the English language. Both amnesic and control participants produced more of the studied, target completions for the stems that could be completed by only a few words than for the stems that could be completed by many words, and the amnesic patients showed a greater difference between the two conditions.

Thus, like explicit memory, implicit memory is affected by the number of potential responses to the memory cue, as demonstrated both by non-memory-impaired participants using indirect instructions and by amnesic patients whose explicit memory is impaired. Another factor that affects the degree of interference in explicit memory is the relative strength of the target versus the nontarget information. When the target information is relatively well learned (and thus relatively strong) in comparison with potentially competing nontarget information, interference is at a minimum (see, e.g., McGeogh, 1942; Melton & Irwin, 1940; Underwood, 1957). For example, the more a target list is studied relative to a nontarget list, the less the nontarget list will interfere with target-list recall. On explicit cued-recall tests, stronger cues (those more likely to elicit the target word in the absence of prior study) lead to better recall of the target item (e.g., Nelson et al., 1987, 1989; see Nelson et al., 1992, 1998, for reviews).

Tests of implicit memory are likewise affected by the relative strengths of the targets and their competitors. For example, indirect word fragment completion tests are influenced by the strength of the fragment cue, where strength is defined by the proportion of people in a norming study who generated the target without prior study (Nelson et al., 1987). For example, S_A_E is a relatively strong cue for SHARE because 20% of people presented with S_A_E without having earlier studied a relevant completion produced SHARE as a response. In comparison, S_A_E is a relatively weak cue for STAKE because only 6% of the people in the norming study produced STAKE as a response. Nelson et al. (Experiment 3) examined the effects of fragment cue strength on an indirect test. After studying a list of words, participants were given fragments that were either strong or weak cues for the studied words and were asked to complete each fragment with the first word that came to mind. Consistent with a competition explanation, weak cues led to lower production of studied items than did strong cues. When the target's relation to the cue was weak, other, nontarget responses were more likely to be produced than when the target was strongly related to the cue.

Neighborhood frequency effects provide additional evidence for the influence of relative target–competitor strength on implicit memory. A word's "neighborhood" is defined as the number of words differing from it by only one letter (for example, CAT and TAR would be part of the neighborhood for CAR, but not for each other). A word's frequency refers to its frequency of occurrence or usage in the language (e.g., as measured through the Kucera & Francis, 1967, norms) and can be used as a rough measure of its preexisting strength. The neighborhood frequency effect refers to the finding that the existence of at least one neighbor with a higher frequency (i.e., strength) than the stimulus word impedes processing of the stimulus word (e.g., Grainger, O'Regan, Jacobs, & Segui, 1989).

In tasks such as lexical decision (in which the participant must quickly decide whether the presented item is a word or nonword) and progressive demasking (in which the target is made gradually less degraded until the participant correctly identifies it), latencies for words with at least one higher frequency neighbor are longer than for those without such a neighbor (Grainger, 1990; Grainger et al., 1989; Grainger & Segui, 1990; Perea & Pollatsek, 1998). The higher frequency neighbor appears to compete with the target, slowing decision time and producing more errors. Performance on these lexical decision and progressive demasking tasks, tasks often used as measures of implicit memory, is impaired by the existence of a competitor stronger than the target.

There is some suggestion that the memory performance of people with amnesia is likewise affected by target–competitor strength. Warrington and Weiskrantz (1974) examined how the stem-cued recall of target words was affected by prior learning of a list of nontarget words that could also complete the stem. They found that control and amnesic participants were equally affected by interference when the stem could potentially be completed by many (eight or more) common words in addition to the studied nontarget and the target (Experiment 3). In contrast, amnesic participants showed larger interference effects from the prior list than did controls when the stem could only be completed by either the target or the studied nontarget (e.g., ENO– can only be completed by ENOUGH or ENORMOUS). In this case, amnesic patients performed at almost chance levels on the second list and did not improve even after several learning and recall trials (Experiment 5). Warrington and Weiskrantz suggested that the interference effects were greater in this experiment because the competition between the target and the studied nontarget (from the first list) was relatively strong, as they were the only possible responses to the stem. In this experiment, amnesic participants had more difficulty overcoming interference caused by a strong competitor than did normal controls.

In summary, preliminary evidence from the performance of amnesic and control participants on tasks commonly used as measures of implicit memory (e.g., word fragment completion, word stem completion, lexical decision, naming) has suggested that interference in implicit memory, as in explicit memory, is affected both by the number of items that compete with the target and by the strength of those competing items relative to the target. We note that most of the evidence for the influence of competitor number and strength comes from investigations of existing language habits, that is, of competitors that originate from preestablished, extraexperimental memories. These effects of preexisting knowledge on both explicit and implicit tests are well described by the Processing Implicit and Explicit Representations (PIER2) model (Nelson et al., 1998). The principles used in PIER2 are largely consistent with the views presented here, but it remains to be seen whether manipulating the number and strength of nontargets introduced during the course of an experiment will also have the same effects on implicit as on explicit memory.

Interference, Memory, and the Brain

Is implicit memory immune to interference? No. For both implicit and explicit memory, interference occurs when similar nontargets compete with the target as potential responses to the memory cue. Further, the degree of interference on both implicit and explicit tests is influenced by the number of competing items and their relative strength. Interference has an important impact on the success of retrieval, regardless of whether that retrieval is deliberate. As a result, any successful model of memory must be able to account for interference phenomena. Below, we consider how a number of theoretical frameworks could address issues of interference in implicit memory and how these conclusions might relate to structures in the brain.

For example, the PIER2 model (Nelson et al., 1998) describes the effects of preexisting, language-based knowledge using principles analogous to those used here to describe the effects of *information* introduced during an experiment.[5] As such, these views are quite consistent with classic interference accounts of forgetting (e.g., Postman & Underwood, 1973; Underwood & Postman, 1960). Models of source memory (e.g., M. K. Johnson, Hashtroudi, & Lindsay, 1993) are also useful in accounting for explicit and implicit retrieval phenomena, with source sometimes serving as a basis on which otherwise similar items can be distinguished and at other times providing a basis for similarity and thus interference. For example, in the Winocur et al. (1996) experiment, list membership (List 1: BEE–HONEY; List 2: BEE–WASP) could be used on the explicit test to distinguish the two similar responses from each other. As a result, interference was less on the explicit test than on the implicit test, where source did not play a role. In contrast, in the Graf and Schacter (1987) experiment, the various response words (WINDOW, EDGE, FINGER, ENERGY, etc.) were similar in that they were all members of the studied set. As a result, interference was greater on the explicit test than on the implicit test, where source (i.e., membership in the study list) did not play a role.

The conclusion that interference has parallel effects in implicit and explicit memory is relevant not only to behaviorally based theories of memory but also to those that explore the brain structures involved in memory. The evidence reviewed above clearly shows that attempts to use dissociations between implicit and explicit memory tasks as evidence that implicit and explicit memory rely on distinct memory systems in the brain (e.g., Moscovitch, 1992, 1994; Schacter et al., 1993; Squire, 1992a; Tulving & Schacter, 1990) cannot rely on dissociations based on interference proneness. A variety of investigations have shown that interference, a major source of forgetting in explicit memory (M. C. Anderson & Neely, 1996; Crowder, 1976; Keppel, 1968; Postman & Underwood, 1973; Underwood, 1945), can also affect implicit memory (e.g., Lustig & Hasher, 2001; Nelson et al., 1989; Ratcliff & McKoon, 1997; Winocur et al., 1996). Furthermore, those investigations that have directly compared interference effects on the same tasks under explicit versus implicit memory conditions have variously found more evidence for interference in explicit memory than in implicit memory (Graf & Schacter, 1987), equivalent interference for both forms of memory (Nelson et al., 1989), or more evidence for interference in implicit memory than in explicit memory (Winocur et al., 1996). Thus, whatever differences may exist between explicit and implicit memory, vulnerability to interference is not among them.

However, the various tests of explicit and implicit memory clearly do tap into different forms of information and perhaps different methods of processing that information. If nothing else, by definition explicit memory requires intentional or at least conscious retrieval of past experience, whereas implicit memory is defined by unintentional, nonconscious retrieval (e.g., Graf & Schacter, 1985; Schacter, 1987). To the extent that these different

[5] Although most empirical studies at that time focused on laboratory-introduced competitors, classic interference theorists assumed that preexisting knowledge and language habits had a similar influence on retrieval (e.g., Postman, 1962; Underwood & Postman, 1960; Underwood & Schulz, 1961). The important work on target and cue set size and strength done by Nelson and colleagues (e.g., Nelson et al., 1992, 1998) has been valuable in verifying these ideas.

information forms and processing methods rely on different brain areas, so too will the procedures that test them. (Likewise, within the explicit and implicit domains, different test procedures may tap different information forms and processes and thus activate different brain areas. See, e.g., Cabeza et al., 1997, for a comparison of free recall and recognition, both commonly accepted as tests of explicit memory.)

Historically, neuropsychological examinations of amnesic patients have been very important in the study of implicit memory (e.g., Scoville & Milner, 1957; Warrington & Weiskrantz, 1974, 1978). More recently, functional neuroimaging techniques have been used to examine the brain areas underlying explicit and implicit memory functioning in healthy participants (e.g., Schacter & Buckner, 1998). However, to our knowledge the only neuroscience model to address the question of interference in implicit memory in any detail is the component process model (Moscovitch, 1992, 1994). Below, we describe how interference in implicit memory has been previously discussed within the context of this model and suggest an alternative interpretation, one based on the similarity between target and nontarget responses.

The component process model (Moscovitch, 1992, 1994) includes (a) highly specialized neocortical "modules" that process and store information specific to their respective domains in perceptual or semantic records (also called *engrams*), (b) a hippocampal component that binds or integrates the engrams from these modules into a memory trace and assigns consciousness, and (c) a frontal component that works with memory to organize and control information flowing to and from the hippocampal component.[6] The frontal component may also play some role in engram formation and reactivation (Moscovitch & Winocur, 1995). In implicit memory, test cues are thought to reactivate the perceptual and semantic records stored in the neocortical modules without invoking the hippocampal component. For explicit memory to occur, the hippocampal component must be invoked, activating associative memory traces that the frontal component then inspects and works with to guide further memory searches, thoughts, or behavior.

Moscovitch (1994) noted that animals with hippocampal damage are very vulnerable to interference, and thus the model would predict that implicit memory, thought not to rely on the hippocampal component, would be vulnerable to interference. However, his review of the human literature revealed both consistent (Mayes et al., 1987; Winocur et al., 1996, then in press) and contradictory findings (Graf & Schacter, 1987). To resolve this contradiction, Moscovitch suggested that perceptually based tests (e.g., the stem completion test used by Graf & Schacter) were immune to interference, whereas conceptually based tests (e.g., the word association tests used by Mayes et al. and Winocur et al.) were especially vulnerable to interference.

However, there are several problems with using a perceptual–conceptual distinction to explain contradictory findings regarding implicit memory's vulnerability to interference. First, there is no strong reason to make this prediction on the basic principles of the model. Second, at least two studies cited in the present review found interference on a perceptual test, word fragment completion (Lustig & Hasher, 2001; Nelson et al., 1989). Therefore, we offer a different interpretation, one based on (a) the component process model's suggestion that implicit memory cues activate only domain-specific perceptual and semantic records, not information about context or associations and (b) the present article's suggestion that interference depends on whether target and nontarget items are similar in such a way that they compete as potential responses.

By our interpretation, the presence of interference on implicit tests depends on how many records are reactivated by the cue. If the cue reactivates the record for the target item only (e.g., in Graf & Schacter, 1987, WIN- likely activates only WINDOW, not FINGER, ENERGY, etc.), then other studied items will not compete with the target and interference will not be seen. However, if the cue is relevant to multiple studied items, both targets and nontargets (e.g., in Nelson et al., 1989, _EEL is relevant for both HEEL and PEEL), the records for both target and nontarget items will be reactivated and compete as potential responses, producing interference.

Whereas implicit memory depends on the reactivation of domain-specific neocortical records in response to a cue, explicit memory requires reactivation of associative traces in the hippocampus (Moscovitch, 1992, 1994). These traces bind together the perceptual and semantic output of the modules, multimodal information about spatial and temporal context, and other elements of the event that make it conscious. Thus, we suggest that the memory traces for target and nontarget items could be similar on—and thus compete on—any of these grounds, including membership in the study episode, leading to interference. However, the memory traces may also contain information that differentiates target from nontarget items (e.g., membership in List 1 vs. List 2), and the frontal lobe can use this information to aid selection, reducing interference.

Thus, our interpretation offers an explanation for the various findings regarding interference in implicit memory that is more consistent with the basic principles of interference theory and the component process model than is a perceptual–conceptual distinction. When the cue on an implicit memory test only activates the record for one studied item, the target, interference will be less than on an explicit test, which activates associative traces for the target and nontarget that are similar at least in their membership in the study episode, if not on other grounds. This was the case for Graf and Schacter (1987), where the stem for the implicit test was relevant only to the target (e.g., WIN- for WINDOW), but the explicit instruction to retrieve a studied word was also relevant to nontargets (e.g., EDGE, FINGER). In contrast, if the cue on the implicit memory test activates the records for both target and nontarget items, interference may be greater than on an explicit test if the explicit test includes information that can differentiate target from nontarget items. This was the case for Mayes et al. (1987) and Winocur et al. (1996), where the stimulus word for the implicit test was relevant to both target and nontarget items (e.g., BEE- for

[6] The model also contains a basal-ganglia component that contributes to sensorimotor or procedural memory. This aspect of the model is not described at length in its original outline, particularly with regards to interference, and we do not discuss it further here. However, we note that there is some suggestion (e.g., Heydeman, Hoffman, & Schmidt, 1991) that similarity can also contribute to interference in skill learning and related domains.

HONEY and WASP), but the explicit test informed the participants which list (1 or 2) contained the target.[7]

Summary and Conclusions

The question of whether implicit memory can be affected by interference has been unresolved for some time, with many researchers and reviewers favoring the interpretation that implicit memory is immune to interference (see reviews by M. C. Anderson & Neely, 1996; Hardcastle, 1993, 1996; Roediger & McDermott, 1993; Rovee-Collier, 1997; Schacter et al., 1993; Tulving & Schacter, 1990). This conclusion was based on the findings of several highly influential studies (Graf & Schacter, 1987; Jacoby, 1983; Sloman et al., 1988) that found no evidence for interference on implicit memory tests under circumstances that, on their surface, typically lead to interference on explicit memory tests. Because interference is a primary source of forgetting in explicit memory, the potential immunity of implicit memory represents an important dissociation, as well as a key boundary condition for interference effects. However, the results of several other investigations (Lustig & Hasher, 2001; Nelson et al., 1989; Ratcliff & McKoon, 1997; Winocur et al., 1996) suggest that interference can occur in implicit memory. Further, brain-damaged patients whose memory performance relies largely on implicit memory (as well as animals with analogous lesions) are often quite vulnerable to interference (e.g., Mayes et al., 1987; Nadel, 1994; Shapiro & Olton, 1994; Winocur et al., 1996).

To resolve the question of whether interference can occur in implicit memory, we reconsidered the implicit memory findings (Graf & Schacter, 1987; Jacoby, 1983; Mayes et al., 1987; Lustig & Hasher, 2001; Nelson et al., 1989; Ratcliff & McKoon, 1997; Sloman et al., 1988; Winocur et al., 1996) in the light of the classic literature on interference in explicit memory. A fundamental finding in that literature is that interference occurs when target and nontarget items are similar in a way that makes them potential responses to a memory cue (Underwood, 1945; see also reviews by Crowder, 1976; Keppel, 1968; Underwood, 1957). Consistent with that finding, implicit memory studies that used similar targets and nontargets (Lustig & Hasher, 2001; Mayes et al., 1987; Nelson et al., 1989; Ratcliff & McKoon, 1997; Winocur et al., 1996) have found evidence for interference, whereas implicit memory studies that used dissimilar targets and nontargets (Graf & Schacter, 1987; Jacoby, 1983; Sloman et al., 1988) did not. Thus, for both explicit and implicit memory, similarity appears to be a critical factor in determining whether interference will occur.

In the explicit memory literature, two other factors influence interference: the number of items competing with the target and the strength of these competing items relative to the target (see, e.g., J. R. Anderson, 1974, 1976; Keppel, 1968; Keppel & Underwood, 1962; McGeogh, 1942; Melton & Irwin, 1940; Postman & Riley, 1959; Underwood, 1945, 1957; Watkins & Watkins, 1975). This literature dealt extensively with targets and competitors acquired in the laboratory rather than with preexisting language habits. The influence of the number and strength of laboratory-acquired competitors on interference in implicit memory has not yet received much empirical investigation, it making little sense to investigate factors that might influence a phenomenon thought not to exist. However, the evidence that is available for existing language habits, such as set size and neighborhood frequency effects (e.g., McEvoy et al., 1995; Grainger et al., 1989), suggests that both implicit and explicit memory are affected by the number of competing items and their strength.

Implicit memory is clearly not immune to interference. Like deliberate retrieval, the nondeliberate retrieval of a target item can be disrupted by competition from similar nontargets. Further, the weight of the evidence suggests that for both implicit and explicit memory the degree of this disruption is affected by the number of competing items and their strength relative to the target. Interference in implicit memory does exist, and this phenomenon must be taken into account when describing explicit and implicit memory from a behavioral or neuropsychological perspective.

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[7] As noted above, the M. K. Johnson et al. (1993) model and its later instantiations contain processes similar to those described here. To our knowledge, models of source monitoring have not been used to specifically address the question of interference in implicit memory, though they could be easily modified to do so.

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