Research Article

IMPLICIT MEMORY IS VULNERABLE TO PROACTIVE INTERFERENCE

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Abstract—*We investigated the possibility that implicit memory, like explicit memory, can be disrupted by proactive interference. Participants first viewed a list of words, with nontargets in the first half of the list and targets in the second. Nontargets were either similar in structure (e.g., "ANALOGY") or unrelated (e.g., "URGENCY") to the targets (e.g., "ALLERGY"). After several filler tasks, participants completed an implicit fragment-completion test (e.g., "A_L_ _ GY") for the target items. Participants who viewed similar nontargets completed fewer fragments with target items and made more intrusions than did participants who viewed unrelated nontargets. Together with previous findings, these results suggest that similar nontargets can compete with target items to produce interference in implicit memory.*

The ability to retrieve a desired piece of information from memory is typically disrupted by learning additional information either before or after the critical item. This phenomenon, interference, is a primary source of forgetting and a major focus of memory research (for reviews, see Anderson & Neely, 1996; Crowder, 1976; Keppel, 1968; Postman & Underwood, 1973; Underwood, 1945). However, almost all investigations have focused on interference in explicit memory as measured using "direct" tests, that is, tests of the conscious, deliberate recollection of previous experience (Schacter, 1987). Implicit memory, or changes in performance as measured on "indirect" tests that do not require intentional or conscious recollection of the experience that produced those changes (Schacter, 1987), is generally thought to be immune to interference (see reviews by Anderson & Neely, 1996; Hardcastle, 1993, 1996; Roediger & McDermott, 1993; Rovee-Collier, 1997; Schacter, Chiu, & Ochsner, 1993), although some researchers (e.g., Roediger & McDermott, 1993; Schacter et al., 1993) have called for further investigation.

The conclusion that implicit memory is immune to interference rests largely on the results of three early studies in this tradition. First, Jacoby (1983, Experiment 4) used a word-identification test to examine implicit memory for a series of lists presented one list per day for 5 days. On both immediate and delayed tests, participants showed implicit memory by better identifying studied words than new words when they were briefly flashed on the screen. There was no evidence of either proactive or retroactive interference: The advantage for studied words did not decline as a function of the number of lists learned on previous or subsequent days. Likewise, Sloman, Hayman, Ohta, Law, and Tulving (1988) found that implicit memory tested using a word-fragment-completion test (e.g., an improved ability to complete the fragment "_AR_VA_ _" after studying "AARDVARK") was not impaired either by having studied many other words or by completing another verbal task between study and test, manipulations that typically lead to interference in explicit memory.

Graf and Schacter (1987) used a paired-associates task to investigate whether explicit and implicit memory differed in their vulnerability to interference. Participants learned critical lists of stimulus-response word pairs (e.g., "shirt-window"), as well as additional lists in which the stimulus word from some pairs 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 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 condition showed interference from having studied multiple response words; participants in the implicit condition completed the stem with the critical response word equally often regardless of whether or not other response words had also been studied.

Taken together, these findings (Graf & Schacter, 1987; Jacoby, 1983; Sloman et al., 1988) appear to provide clear evidence that whereas interference is a major source of forgetting in explicit memory, implicit memory is immune to interference. Along with other dissociations (e.g., amnesiacs have impaired explicit memory but often intact implicit memory, explicit and implicit memory are often affected differently by manipulations of levels of processing; see Roediger & McDermott, 1993, for review), this difference has been used to argue that explicit and implicit tasks measure different forms of memory, and may even rely on different systems in the brain (e.g., Schacter, 1998; Squire, 1993; Tulving & Schacter, 1990).

The suggestion that implicit memory may be immune to interference is widely cited in the literature (e.g., Anderson & Neely, 1996; Hardcastle, 1993, 1996; Roediger & McDermott, 1993; Rovee-Collier, 1997; Schacter et al., 1993). However, there are at least two inconsistent findings. First, Nelson, Keelean, and Negrao (1989, Experiment 2) found that regardless of whether implicit or explicit instructions were used at test, participants were less likely to complete a word fragment (e.g., "_EEL") with a particular studied word (e.g., "HEEL") after also studying a structurally similar word (e.g., "PEEL") than after studying a meaningfully related (e.g., "SHOE") or unrelated (e.g., "COARSE") word. In a later experiment, Winocur, Moscovitch, and Bruni (1996, Experiment 2) asked participants to learn two lists of semantically related paired associates (e.g., List 1 included "bee-honey" and List 2 included "bee-wasp"). Later, participants were presented with the stimulus word (e.g., "bee-"), and were told to respond either with a word from the first list (explicit condition) or with the first related word that came to mind (implicit condition). Participants tested under explicit conditions were more likely to produce a first-list word

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than were participants tested under implicit conditions, who produced an almost equal number of words from the two lists. These results suggest greater interference in implicit memory than in explicit memory, directly contradicting those of Graf and Schacter (1987).[1]

However, these two studies (Nelson et al., 1989; Winocur et al., 1996) do not provide conclusive evidence that the ability to retrieve the critical item was disrupted. The implicit tests used in these studies instructed participants to produce "the first word that came to mind" in response to the cue; the instructions did not designate one of the studied items as the target to be produced. Therefore, from the participants' point of view, any response that fit the cue was acceptable: For example, participants in the implicit condition of the experiment by Nelson et al. did not know that "HEEL" was the target response for the fragment "_EEL." Instead, to these participants, either "HEEL" or "PEEL" (or any other word that fit the fragment) seemed a legitimate response, although unbeknownst to them, the experimenter counted only "HEEL" as "correct." Participants who were in the implicit condition and studied both words might therefore sometimes produce "HEEL" and sometimes produce "PEEL," but this does not necessarily mean that their ability to retrieve "HEEL" was disrupted. Thus, although the results of these studies meet a behavioral definition of interference in terms of reduced responding from a particular list (similar to results found using the modified free-recall, MFR, procedure in the classic interference literature), they do not directly address whether retrieval of the critical item would be impaired had that item been specifically asked for (as in standard cued recall or the modified modified free-recall, MMFR, procedure; see Barnes & Underwood, 1959).[2] In addition, neither of these studies attempted to ensure that participants were not using conscious, deliberate retrieval of the studied items. If performance on these nominally implicit tests were influenced by explicit memory, it would not be surprising that interference was found.

Thus, the question of whether implicit memory is vulnerable to disruption from interference is open, with the bulk of the evidence favoring the common interpretation that implicit memory is immune to interference. However, an examination of the materials used in the investigations of this question reveals an interesting dichotomy: Those studies that found evidence suggesting that interference can occur in implicit memory (Nelson et al., 1989; Winocur et al., 1996) used nontarget items that were similar to the critical items on dimensions that made the nontarget items legitimate responses to the test cue (e.g., nontarget "PEEL" and target "HEEL" for "_EEL"; nontarget "wasp" and target "honey" for "bee-"). In contrast, those studies (Graf & Schacter, 1987; Jacoby, 1983; Sloman et al., 1988) that did not find evidence for interference used nontarget responses that were not similar to the critical items (e.g., nontargets "energy," "finger," etc., and target "window" for "win-").

This difference in materials is potentially important because interference depends critically on similarity between target and nontarget responses (Underwood, 1945). For example, memory for a critical list of words will not be impaired by studying a list of numbers, but it will be impaired by studying another list of words, and this impairment will increase if the additional list is composed of synonyms of the critical list (Johnson, 1933; McGeogh & McDonald, 1931). This raises the question of whether implicit memory might also be impaired by interference if the nontarget items are similar to the critical items.

To answer this question, we used a set of materials (adapted from Smith & Tindell, 1997) in which each fragment presented at test could be completed only by one previously presented target word (e.g., "A_L_ _GY" can be completed only by "ALLERGY"), and varied the nature of the also-presented nontarget word. For control participants, the nontarget words were unrelated to the test fragments (e.g., "URGENCY"). For experimental participants, the nontarget words had a structure similar to that of the target words, so that they seemed like potential completions (e.g., "ANALOGY" for "A_L _ _ GY"). Target and nontarget words were presented as part of a list used in a vowel-counting task, with nontarget words in the first half of the list and target words in the second. After several filler tasks, participants completed the fragment test under implicit conditions, without reference to the previously presented words. Performance for these two critical groups was compared with that of a baseline group, who completed only the fragment test (without exposure to any list items).

Our predictions were straightforward: If interference does not occur in implicit memory, then fragment-completion performance in the two critical conditions would be equivalent. In contrast, if competition from similar nontarget items can lead to interference in implicit memory (as it does in explicit memory), fragment completion would be lower in the experimental than in the control condition. Both groups were expected to show priming relative to the baseline condition. The data showed clear evidence for interference on this implicit test.

METHOD

Design

This study used a three-group design, with the critical groups defined by the nature of the nontarget items. For the interference group, the nontarget items (e.g., "ANALOGY") were structurally similar to the correct completions (e.g., "ALLERGY") of test fragments (e.g., "A _ L _ _ GY"). For the control group, the nontarget items (e.g., "URGENCY") were unrelated to the test fragments. These two groups received the same target items, filler tasks, and test fragments. The third, baseline, group received only the test fragments.

Participants

One hundred forty-six Duke University undergraduates participated in this experiment. Participants were randomly assigned to the three groups until there were 32 participants per group. Data from 10 participants were replaced because of low verbal ability (less than 13 points of a possible 48 on the Extended Range Vocabulary Test, Version 3; Educational Testing Service, 1976) or experimenter error. Data from 40 participants were replaced because those participants indicated an awareness of the relation between the encoding and test phases of the experiment.

Materials and Procedure

Participants in the control and interference conditions first viewed a list of words, divided for experimental purposes into two halves. The

1. See Experiment 1 in Winocur et al. (1996) and Mayes, Pickering, and Fairbairn (1987) for similar results using amnesic patients.

2. The MFR procedure asked participants to give the first studied response that came to mind. The MMFR procedure asked for all responses. Thus, failure to produce the target response in the MMFR procedure would provide stronger evidence for impaired retrieval.

first half of the list contained the nontarget items; the second half of the list contained the target items. This list was followed by several filler tasks, after which participants in the two groups completed a word-fragment test, with the critical word fragments corresponding to target items from the second half of the presentation list. The word-fragment test was followed by an awareness questionnaire and free-recall test. Participants in the baseline condition completed only the word-fragment test. All participants completed the Extended Range Vocabulary Test (Educational Testing Service, 1976) after the word-fragment test.

The presentation list for the targets and nontargets consisted of 30 seven-letter words individually presented in the center of the screen. The participant's task was to count the number of vowels in each word and press a key corresponding to that number. The list began with 3 buffer items, followed by 12 nontarget items, 12 target items, and 3 ending buffer items. The buffer items were unrelated to the targets and began with different letters than any other words in the list. For participants in the interference condition, each of the 12 nontarget items was orthographically similar to one of the target items, beginning with the same letter and sharing four or five letters with that word. For participants in the control condition, the 12 nontarget items were unrelated to the 12 target items and began with different letters. (See Table 1.)

The materials for the presentation list and critical fragments test were modified from those used by Smith and Tindell (1997). For half of the participants, the target items and corresponding fragments were those used by Smith and Tindell (e.g., "ALLERGY," "A _ L _ _ G Y"). These participants were divided evenly into the interference and control conditions. For participants in the interference group, the nontarget items were the interference primes used by Smith and Tindell (e.g., "ANALOGY"). For participants in the control group, the nontarget items were words unrelated to the target words (e.g., "URGENCY"). The lists were reversed for the other half of the participants, so that their target items were the interference primes (e.g., "ANALOGY") used by Smith and Tindell.

Table 1. *Nontargets, targets, and critical word fragments (adapted from Smith & Tindell, 1997)*

Nontarget lists			
Control condition	Interference condition	Target list (all participants)	Test fragments (all participants)
Set A			
URGENCY	ANALOGY	ALLERGY	A_L_ _GY
GAZELLE	BRIGADE	BAGGAGE	B_G_A_E
RESERVE	COTTAGE	CATALOG	C_TA_ _G
IMPULSE	CHARTER	CHARITY	CHAR_T_
NEGLECT	CLUSTER	COUNTRY	C_U_TR_
PADDOCK	CRUMPET	CULPRIT	CU_P_ _T
WEDDING	DENSITY	DIGNITY	D_ _NITY
KEYHOLE	FIXTURE	FAILURE	F_I_URE
SEGMENT	HOLSTER	HISTORY	H_ST_R_
SOLDIER	TONIGHT	TANGENT	T_NG_ _T
ENTROPY	TRILOGY	TRAGEDY	TR_G_ _Y
REGIMEN	VOYAGER	VOLTAGE	VO_ _AGE
Set B			
URGENCY	ALLERGY	ANALOGY	A_ _L_GY
GAZELLE	BAGGAGE	BRIGADE	B_ _GADE
RESERVE	CATALOG	COTTAGE	C_T_AG_
IMPULSE	CHARITY	CHARTER	CHART_ _
NEGLECT	COUNTRY	CLUSTER	C_U_T_R
PADDOCK	CULPRIT	CRUMPET	C_U_P_T
WEDDING	DIGNITY	DENSITY	D_N_ITY
KEYHOLE	FAILURE	FIXTURE	FI_ _URE
SEGMENT	HISTORY	HOLSTER	H_ _ST_R
SOLDIER	TANGENT	TONIGHT	T_N_G_T
ENTROPY	TRAGEDY	TRILOGY	TR_ _ _GY
REGIMEN	VOLTAGE	VOYAGER	VO_AGE_

The fragment-completion test consisted of 70 word fragments: 12 critical fragments corresponding to the target words and 58 filler fragments that did not correspond to studied words. The critical fragments (see Table 1) were created by deleting from the target word the two or three letters not shared with the orthographically similar nontarget (e.g., target "ALLERGY," nontarget "ANALOGY," fragment "A_ L _ _ GY"). Filler fragments were created by deleting two or three letters from seven-letter words that were not on the presentation list.

Five filler fragments appeared at the beginning and end of the test. The remaining fragments were arranged in blocks of five (four fillers and one critical fragment). The critical fragment could occur at any position within a block, with the restriction that no two critical fragments could occur consecutively. Fragments were individually presented in the center of the screen for 1 s.

Two filler tasks intervened between the presentation list and the critical fragments test. These tasks were chosen because they had a "fill in the blank" aspect similar to the fragments test, reducing the likelihood that participants would become aware of the connection between the presentation list and critical fragments. The first filler task was the Elaborations Test from the Educational Testing Service's (1976) manual. Participants were given two pages filled with line drawings of cups and neckties and had 2 min per page to draw different designs on as many items as possible. The second filler task was a name-fragments task. Twenty-five names with missing letters (e.g., "D _ R O T _ Y") were individually presented in the center of the screen for 1 s. Participants were to say the correct name out loud.

Several other steps were taken to ensure that the results from the word-fragment task were not influenced by deliberate retrieval. First, no mention of the previously presented list was made in the instructions for the fragment test. Instead, participants in both the baseline and the critical conditions were told that they would see words that were missing letters, as in a crossword puzzle, and that they were to say the correct word aloud as quickly as possible. Second, immediately after completing the fragment test, participants in the critical conditions were asked a series of awareness questions. Data from participants who noticed a connection between the fragment-completion test and the earlier vowel-counting task were excluded and replaced with data from unaware participants.

RESULTS AND DISCUSSION

Fragment-completion data were analyzed using planned comparisons between the baseline group and each of the two critical groups (control and interference), and between the two critical groups.

The critical question was whether orthographically similar nontargets impaired implicit memory for the target words. The answer is "yes." (See Fig. 1.) Priming was above baseline for both the control group, $t(62) = 5.96$, $p = .0001$, and the interference group, $t(62) =$

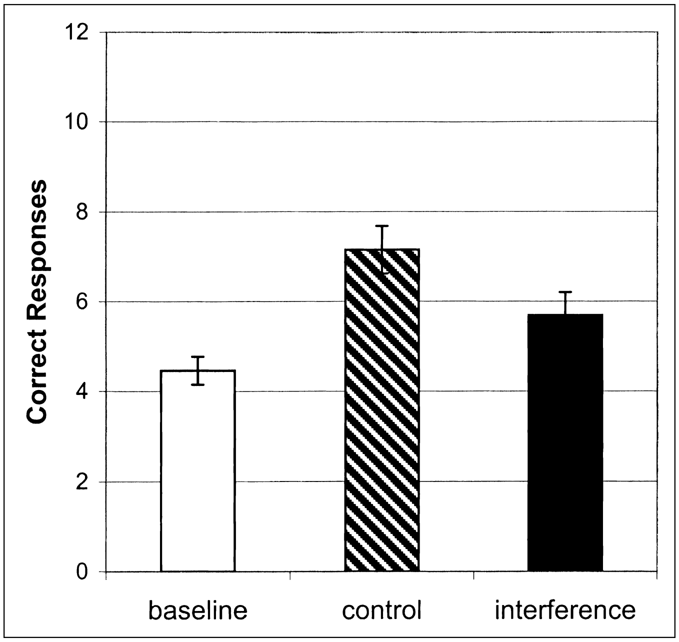

Fig. 1. Mean number of correct completions, by group.

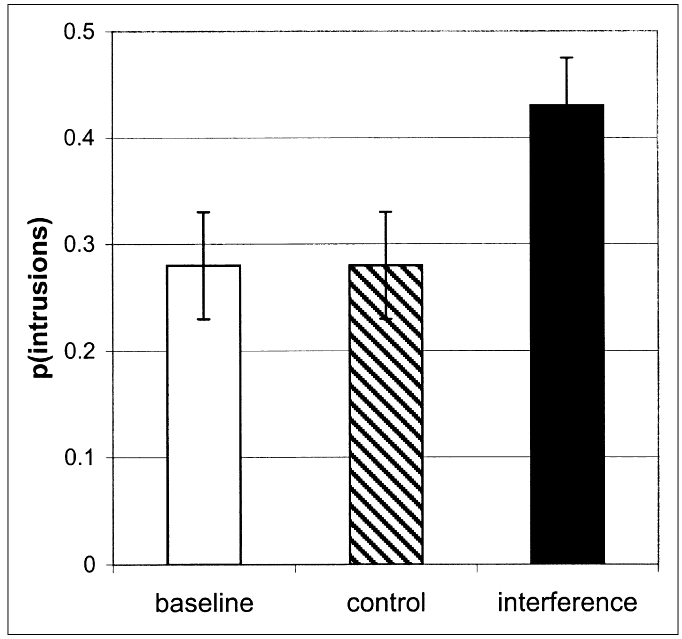

Fig. 2. Mean proportion of incorrect responses that were direct intrusions of the similar nontarget, by group.

2.78, $p = .007$, but the interference group completed fewer critical fragments than did the control group, $t(62) = 3.18$, $p = .002$. The effect-size index d for the difference between the control and interference groups was 0.71, near the standard (0.80) suggested by Cohen (1988) for a "large" effect. Both groups (control and interference) who had viewed the target words showed implicit memory, as demonstrated by higher rates of fragment completion than the baseline group, but for the interference group the benefit of prior exposure to the target completions was reduced by additional exposure to similar nontargets. These data clearly show that implicit memory for target items can be affected by interference from prior exposure to similar, nontarget items that compete as potential responses to the test cue.

We also examined the proportion of incorrect responses that were direct intrusions of the nontarget word. If the lower performance by the interference group was caused by competition from the similar nontargets, that group might show more intrusions of the similar nontargets on the word-fragment test. The data were consistent with this expectation. (See Fig. 2.) The control group produced no more intrusions than did the baseline group, but the interference group produced many more intrusions than either of the other two groups, $t(62) = 3.03$, $p = .003$, $d = 0.76$, for both comparisons.

It is unlikely that the interference effect found here is the result of participants' using conscious recollection to complete the task, as we took several steps to avoid contamination from explicit memory (Roediger & McDermott, 1993). The target and nontarget items were presented under incidental conditions (no mention of a later memory test), and the processing task (counting vowels) was shallow. Between list presentation and the critical fragments test, we inserted filler tasks that made it seem as though the critical fragments test was one in a series of fill-in-the-blank tests, rather than a memory test with any relation to the previously presented words. The low proportion of fragments corresponding to previously presented words (less than 20%) and the fast presentation rate (one fragment per second) further reduced the probability that participants would engage in deliberate retrieval. Finally, we excluded data from participants who noticed a connection between the fragment test and the previously presented words. These measures help ensure that the results reported here are reflective of implicit memory, that is, memory without conscious recollection (Schacter, 1987). In addition, performance on the final free-recall test was at floor for both the interference and the control groups (mean number of words recalled correctly = 0.50 vs. 0.47, $t < 1$), with most participants unable to recall any words. Thus, it is unlikely that any attempts to use explicit memory would have been effective.

We asked aware participants whether they had tried to either use or avoid items from the vowel-counting task, and the majority (12 control, 18 interference) replied that they simply used the first word that came to mind. These participants showed interference effects consistent with those found for unaware participants (correct items: $M = 7.42$ for control participants, 6.38 for experimental participants, $d = 0.60$; probability of intrusions: $M = .22$ for control participants, .41 for experimental participants, $d = 0.96$). Those few participants (4 control, 6 experimental) who attempted to use deliberate retrieval had slightly fewer correct completions and more intrusions overall, but also showed interference (correct items: $M = 6.25$ for control participants, 4.67 for experimental participants, $d = 1.58$; probability of intrusions: $M = .31$ for control participants, .48 for experimental participants, $d = 0.68$).

The similar size of the interference effects found for aware and unaware participants may at first seem at odds with the claim that the unaware participants' data reflect implicit memory rather than deliberate retrieval. However, previous investigations have found that target fragment completion is impaired when only the nontargets are studied (Smith & Tindell, 1997) or when the nontarget is flashed on the screen before the fragment (Logan & Balota, 2000). This occurs even if participants are informed of the detrimental nature of the nontargets. These findings suggest that (at least for these materials) the size of the interference effect is the same regardless of whether explicit or implicit memory is used. However, it should be noted that the current data were obtained using a shallow encoding task and perceptually similar items. Additional experiments (some of which are under way) will be required to determine if the size and nature of the interference effect found here generalize across other encoding (e.g., pleasantness ratings) and testing (e.g., word-association) procedures.

The current results, in combination with the findings of previous studies (e.g., Mayes, Pickering, & Fairbairn, 1987; Nelson et al., 1989; Winocur et al., 1996), demonstrate that explicit memory is not the critical factor in determining the presence of interference. Instead, for both explicit and implicit memory, a critical factor for interference is similarity between targets and nontargets such that they compete as potential responses to a memory cue (see Lustig & Hasher, in press).

The findings of Graf and Schacter (1987) may seem at first to contradict this solution, because they found interference on an explicit test but not an implicit test despite using the same items for both study (e.g., "shirt-finger," "shirt-window," "shirt-energy," etc.) and test (e.g., "shirt-win_"). However, although the same nominal test stimuli were presented for the explicit and implicit tests, the memory cue was functionally different between them. The explicit test instructed participants to retrieve a response word from one of the studied pairs. Thus, for the explicit test, both the stimulus word ("shirt") and the stem ("win-") were relevant aspects of the memory cue. The instruction to retrieve a response term may have brought to mind the multiple words studied in conjunction with the stimulus word (e.g., "shirt-finger," "shirt-window," "shirt-energy"). The response that correctly completed the stem was then selected from this set. Thus, activation of the nontarget items caused by reference to the study episode led to competition between the target item and other studied items, resulting in interference.

In contrast, the implicit test used by Graf and Schacter (1987) did not make reference to the study episode or require participants to consider the stimulus word in finding a completion for the stem; the only requirement was to produce a word that completed the stem. In this case, the stem ("win-") was the only relevant aspect of the memory cue. Because no other words in the experiment began with the same three letters as the target word, no words were similar to the target in a way important for completing the stem. The lack of similarity between target and nontarget items on a test-relevant basis, rather than the use of implicit instructions per se, is likely the reason that interference did not occur.

For quite some time, the general suggestion in the literature has been that implicit memory is immune to interference (e.g., Anderson & Neely, 1996; Hardcastle, 1993, 1996; Roediger & McDermott, 1993; Rovee-Collier, 1997; Schacter et al., 1993). In addition to representing an important dissociation between explicit and implicit memory, this conclusion implied a major boundary condition for interference effects, a primary source of forgetting in explicit memory. The present findings clearly demonstrate that implicit memory is not immune to disruption from interference. Instead, these results combine with those of other recent investigations (e.g., Mayes et al., 1987; Nelson et al., 1989; Winocur et al., 1996) and a long history of classic interference research (see Postman & Underwood, 1973; Underwood, 1945) to suggest that a critical boundary condition for interference is similarity between critical and nontarget items, not deliberate retrieval (see Lustig & Hasher, in press).

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