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Retrieval-induced forgetting: Evidence for a recall-specific mechanism

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Previous work has shown that recalling information from long-term memory can impair the long-term retention of related representations—a phenomenon known as retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994). We report an experiment in which the question of whether retrieval is necessary to induce this form of impairment was examined. All the subjects studied six members from each of eight taxonomic categories (e.g., *fruit orange*). In the competitive practice condition, the subjects practiced recalling three of the six members, using category-stem cues (e.g., *fruit or*____). In the noncompetitive practice condition, the subjects were reexposed to these same members for the same number of repetitions but were asked to recall the category name by using the exemplar and a stem as cues (e.g., *fr*____ *orange*). Despite significant and comparable facilitation of practiced items in both conditions, only the competitive practice subjects were impaired in their ability to recall the nonpracticed members on a delayed cued-recall test. These findings argue that retrieval-induced forgetting is not caused by increased competition arising from the strengthening of practiced items, but by inhibitory processes specific to the situation of recall.

David Starr Jordan, one-time president of Stanford University and distinguished professor of ichthyology, was rumored once to have said "Every time I learn the name of a student, I forget the name of a fish." Jordan's remark is amusing because it suggests a feeling that we have all had from time to time—a sense of being limited in the knowledge we can maintain in a highly accessible state. Such knowledge resides outside of working memory but, nevertheless, remains in a state poised precariously at the periphery of awareness, ready, by virtue of frequent or recent use, to be handily dispensed. The present paper is concerned with these limitations on retrieval access and with the memory mechanisms that produce them. Our claim is that these limitations are not produced by the mere encoding of new knowledge but, rather, by its retrieval.

Retrieval as a Cause of Forgetting

Retrieval processes can have a substantial impact on the long-term accessibility of items in memory. Although a successful retrieval can facilitate later recall of the retrieved items (see, e.g., Allen, Mahler, & Estes, 1969; Bjork, 1975; Carrier & Pashler, 1992; Gardiner, Craik, & Bleasdale, 1973), there is now abundant evidence establishing a more paradoxical feature of human memory: Sometimes, the act of remembering can cause forgetting. Often, recalling an event or fact impairs our later ability to recall related knowledge. In a recent study by Anderson, Bjork, and Bjork (1994), subjects performed *retrieval practice* on three target members from each of several previously studied six-item categories (e.g., fruits, drinks). Such retrieval practice consisted of retrieving these three exemplars three times in response to category-plus-stem cues (e.g., *fruit or* ___ for the item *orange*). Following practice, subjects were less likely to recall the remaining three nonpracticed exemplars (e.g., *fruit banana*) on a later retention test. This deficit in the recall of related information was not short-lived, lasting at least 20 min beyond the retrieval practice session in which it was induced. Other studies using this paradigm have shown that this form of forgetting is not limited to semantic categories or even to word lists, but also occurs in the recall of visuospatial materials (Ciranni & Shimamura, 1999) and even in the recall of complex eyewitness events (Shaw, Bjork, & Handal, 1995). These observations of long-lasting retrieval-based impairment, together with research on output interference in episodic recall (Roediger, 1974; Roediger & Schmidt, 1980; Smith, 1971, 1973; Tulving & Arbuckle, 1963) and semantic recall (Blaxton & Neely, 1983), testify to the existence of a general process by which the act of recall reduces access to related memories (see also Dagenbach, Carr, & Barnhardt, 1990, and Schooler, Fiore, & Brandimonte, 1997, for related phe-

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nomena). To emphasize the generality of this process and its importance in producing long-lasting memory failures, Anderson et al. (1994) have referred to this phenomenon as *retrieval-induced forgetting*.

Although the preceding findings clearly show that retrieval is often *sufficient* to cause forgetting, there has been little work that has examined whether retrieval is *necessary* for these effects to occur. It is possible that the mechanisms underlying retrieval-induced forgetting do not require effortful recall to have their detrimental impact. For instance, many models of interference predict that strengthening the representation of an item by any means (e.g., retrieval practice or additional study) should block retrieval access to related items (see, e.g., Mensink & Raaijmakers, 1988; Rundus, 1973). These models reflect a long tradition of research on associative competition mechanisms as a source of interference (see Anderson & Bjork, 1994, and Anderson & Neely, 1996, for reviews). Blocking of this sort may be thought of in terms of *tip-of-the-tongue* experiences, in which we forget a word or a name, presumably because of persistent intrusions of a highly accessible similar name (Baddeley, 1982; Jones, 1989; Reason & Lucas, 1984; Woodworth, 1938). Consistent with this view, studies using the retrieval practice procedure find that repeated retrieval facilitates later recall of the practiced items. If strengthening items through retrieval practice impairs access to related knowledge, other methods of strengthening (e.g., extra study time or extra repetitions) should be equally disruptive. A finding of impairment under these conditions would argue that recall may not be a necessary condition for this form of forgetting.

Although retrieval-induced forgetting does not *necessarily* speak to the existence of recall-specific forgetting mechanisms, several properties of this phenomenon suggest that it is produced by inhibitory processes that resolve retrieval interference. Consider the study by Anderson et al. (1994), mentioned previously. Although there was a general tendency for retrieval practice to impair the recall of related knowledge, the degree of impairment depended strongly on the degree to which related items interfered with the retrieval practice of target items. Across three experiments, significant retrieval-induced forgetting was seen for exemplars with high taxonomic frequency (e.g., *fruit banana*), but little or no impairment was found for low-frequency items (e.g., *fruit guava*). This difference in impairment occurred despite significant (and comparable) facilitation in the final recall of practiced items in the two conditions. Thus, the strengthening of practiced items, by itself, does not appear to cause retrieval-induced forgetting; rather, differences in impairment depend crucially on the strength of the unpracticed, related items. On the basis of these findings, Anderson et al. argued that when subjects perform retrieval practice (e.g., *fruit orange*), other exemplars also become activated in proportion to how strongly they are related to the category cue (e.g., *banana* becomes more activated than *guava*). If interference from these items slows retrieval, inhibitory processes suppress the competing items (e.g., *banana*), ultimately impairing subjects' ability to recall them on the delayed retention test. Supporting this view, retrieval-based impairment was recently shown to depend on taxonomic frequency in the context of output interference in episodic recall (Bäuml, 1998).

This inhibition view received strong support from later work by Anderson and Spellman (1995), who argued that if retrieval practice suppresses competing exemplars, those suppressed items should be more difficult to recall from any retrieval cue used to test them. Consistent with this prediction, Anderson and Spellman found that when subjects performed retrieval practice on some exemplars of a category (e.g., *red blood*), delayed recall performance was impaired for other exemplars, regardless of whether those items were tested with the same category cue used to do retrieval practice (e.g., *red tomato*) or a different, unpracticed category cue (e.g., *food strawberry*). Notably, subjects' recall for items tested under the unpracticed category (*food strawberry*) was impaired even though the category cue was unrelated to the item that had been strengthened by retrieval practice (*blood*). Thus, the unpracticed category provided a measure of the accessibility of these related items that was independent of associative interference from the practiced targets. Anderson and Spellman argued that this evidence for cue-independent impairment supports the existence of an attentional inhibition process that suppresses competing items in order to focus the search for retrieval targets.

Recall-Specific Inhibition: Arguments and Evidence

The evidence summarized above shows how retrieval-induced forgetting may be produced by mechanisms that are particular to recall. If inhibitory mechanisms are necessary to resolve retrieval interference, less inhibition should be necessary when subjects do not have to retrieve anything (Anderson & Spellman, 1995). For instance, more inhibition should be observed when subjects actively recall to-be-practiced items from incomplete cues (e.g., *fruit or* ___) than when subjects are merely presented with the to-be-practiced items for additional study. Although subjects may sometimes covertly recall the earlier presentation of an item when it is presented again to them for additional study (Atkinson & Juola, 1974; Jacoby, 1991; Mandler, 1980), the substantial amount of additional cue information available during such representations is likely to greatly reduce interference from related knowledge. Thus, if extra study repetitions present little opportunity to resolve retrieval interference, little inhibition of related memories should occur. That is, even if extra presentations strengthen the repeated items substantially, little impairment should be observed.

Although the foregoing analysis seems plausible, it is possible that inhibitory processes underlying retrieval-induced forgetting are not specifically tied to recall. For instance, extra presentations might suppress related knowledge, either because inhibition does not function to re-

solve interference or because our assumptions about interference in nonrecall situations are incorrect. These possibilities seem unlikely, however, in light of findings that support the existence of a recall-dependent forgetting process. For example, in a study of semantic retrieval, Blaxton and Neely (1983) found that subjects were slower to generate a critical target exemplar from semantic memory (e.g., *fruit a___*) after they had generated four other prime exemplars from that same category (e.g., *fruit o___*). In contrast, subjects were faster, not slower, to generate the same target exemplar when the prime items were presented intact to subjects for speeded naming (e.g., *fruit orange*). If presenting related primes was enough to impair semantic recall of target exemplars, comparable slowing should have been found in both the generate-prime and the read-prime conditions. The key difference between these two forms of prime trial is that in the generate-prime case, subjects had to recall prime items from incomplete retrieval cues, in the face of interference from other similar exemplars—a situation likely to trigger inhibition, and a situation strongly resembling that present in the retrieval practice paradigm.

A second finding supporting the existence of a recall-specific forgetting process was reported by Bäuml (1996) in a study of retroactive interference. The experiment concerned how well subjects could recall a first list of words after having studied several intervening word lists to varying degrees. In the low-interpolation condition, the subjects studied these additional lists at a rate of 2 sec per item, whereas the subjects in the high-interpolation condition studied the lists at a rate of 5 sec per item. After learning the intervening lists, the subjects recalled the initial study list, followed by the additional lists. An abundance of prior work has shown substantial increases in retroactive interference as a function of additional learning on intervening lists (Barnes & Underwood, 1959; see Postman, 1971, for a review). However, most of these classical interference studies used the method of anticipation, in which subjects learn a study list by repeated study–test cycles. As Anderson et al. (1994) noted, this method of learning confounds the amount of intervening learning with the number of opportunities (on test trials) that subjects have in which to suppress responses from the first study list. By manipulating the degree of intervening learning through variations in study time, Bäuml (1996) was able to separate out the effects of additional learning from retrieval practice. Importantly, although Bäuml's (1996) manipulation of study time created strong differences in the final recall of interpolated material, retroactive interference did not vary with the degree of interpolated learning, unlike in classical studies. Thus, there is ample precedent for believing that strengthening study items does not impair the recall of related material, at least in the retroactive interference paradigm (for similar findings in the contexts of proactive interference and of the list strength effect, see DaPolito, 1966, and Bäuml, 1997, respectively).

The Present Study

The findings of Blaxton and Neely (1983) and Bäuml (1996) suggest that the inhibitory process at work in the studies of Anderson et al. (1994) and Anderson and Spellman (1995) may be recall specific. However, two features of these studies limit confidence in this conclusion. First, Blaxton and Neely never measured the degree to which prime exemplars were strengthened by either naming or generation. Because we do not know how much the primes were strengthened, we cannot be sure whether the greater impairment in the generate-prime condition was produced by recall-specific inhibitory processes or by greater strengthening of the generated primes. If generated primes were strengthened more than named primes, greater impairment of target items might reflect increased competition from the primes. Second, although Bäuml's (1996) study shows that variations in strengthening caused by increases in study time did not lead to differences in retroactive interference, it did not directly demonstrate that recall *does* cause variations in impairment. Thus, Bäuml's (1996) study can only speak indirectly to the importance of the recall process in initiating inhibitory mechanisms.

To test for the existence of a recall-specific inhibitory process, we modified the retrieval practice procedure so that we could contrast the effects of two forms of retrieval practice, both of which should strengthen practiced items. In the *competitive retrieval practice* condition, subjects performed retrieval practice with the method developed by Anderson et al. (1994). For each practiced item, the subjects received a category name along with the first two letters of an exemplar (e.g., *fruit or___*). The subjects were asked to recall the earlier-studied item that fit the cues and to write both the category label and the critical exemplar down as responses. If we replicate the findings of Anderson et al., this form of retrieval practice should cause retrieval-induced forgetting.

In the new condition, which we call *noncompetitive retrieval practice*, subjects were instead given the exemplar along with the first two letters of the category name (e.g., *fr____ orange*) as cues for recalling the category label. This new condition allowed us to reexpose to-be-practiced items in a way that eliminated competition from related exemplars but that, nevertheless, matched the two conditions for the presence of a retrieval task. As in the competitive retrieval practice condition, subjects were asked to respond to retrieval practice trials by writing down both the category name and the exemplar. Thus, both groups practiced the same category exemplars for the same number of times, both had to recall something during practice, and both had to write down exactly the same responses.[1] The key difference between these groups concerned whether subjects recalled the critical items or were simply exposed to them in a way that did not require the resolution of interference from related exemplars. If reexposing to-be-practiced items is enough to suppress related exemplars, both competitive and non-

competitive retrieval practice should cause retrieval-induced forgetting. However, if inhibitory processes are specific to the need to overcome retrieval competition, impairment should only occur with competitive practice, even though both forms of practice may significantly strengthen practiced items.

Because both the competitive and the noncompetitive forms of retrieval practice substantially increase the time subjects spend processing the practiced items, both conditions are likely to facilitate recall of those practiced items on the final test. For this reason, it is critical to control the final recall order of exemplars within each category, if we are to evaluate whether retrieval-induced forgetting is recall specific. When subjects are free to recall items in any order, they often recall the stronger practiced items first (Anderson et al., 1994; see also Bousfield & Barclay, 1950; Tulving & Hastie, 1972; Wixted, Ghadisha, & Vera, 1997). Thus, any remaining nonpracticed members will be recalled later, on average, than baseline items, subjecting them to greater output interference. So, even if nonpracticed members were not suppressed by noncompetitive retrieval practice, the substantial facilitation of practiced items in that condition may cause retrieval-based suppression during the final test (see Anderson et al., 1994; Bäuml, 1996, 1997, 1998). These output order biases might lead one mistakenly to conclude that reexposing exemplars during retrieval practice was sufficient to suppress related items.

To solve this problem, we controlled the within-category testing order of exemplars by cuing subjects with the category and a single letter stem for each item (Anderson et al., 1994). This procedure allows us to ask subjects to recall first all the unpracticed items in a category, followed by practiced items, or vice versa. By examining retrieval-induced forgetting for items tested in the first half of a category test, we can measure the effects of the earlier retrieval practice phase in a way that is uncontaminated by output interference from the final recall of practiced items. If repeatedly presenting exemplars in the earlier practice phase is enough to suppress related items, we should observe impairment in the noncompetitive retrieval practice condition. More specifically, impairment should appear not only in overall recall performance, but also when related items are tested in the first half of a category test, showing that such impairment is not a product of output interference. If, on the other hand, suppression is tied to the need to resolve interference during retrieval practice, impairment should only occur in the competitive retrieval practice condition; as in Anderson et al. and Anderson and McCulloch (1999), such impairment should occur not only in overall recall, but also for items tested in the first half of a category test.

METHOD

Subjects and Design

The subjects were 64 undergraduate students, who participated to fulfill a requirement for an introductory psychology course. The experiment was a 2 × 2 × 3 mixed design with type of retrieval practice (competitive vs. noncompetitive) manipulated between subjects, and both within-category testing position on the final recall test (first half of a category test and second half of a category test) and retrieval practice status (practiced, related, and baseline items) manipulated within subjects. The dependent measure was the proportion of items recalled in each condition.

Materials

The materials consisted of six exemplars from each of eight taxonomic categories that were drawn from the Battig and Montague (1969) category norms. Exemplars were constrained to be moderate to high in taxonomic frequency (average rank order of 8 in Battig & Montague, 1969) and low in overall word frequency ($M = 12$ per million in Kučera & Francis, 1967). Every item in the experiment began with a unique two-letter stem, and items within a category each began with a unique letter. The materials were the same as those listed in Appendix B of Anderson et al. (1994); see the Materials section of that paper for a more detailed characterization. Two additional filler categories, mountains and countries, were also included to control for primacy and recency effects.

Learning booklets. Learning booklets were constructed with the 48 experimental and 12 filler items. Items were presented one at a time in category–exemplar paired associate format (e.g., *fruit orange*). The order of exemplars within a booklet was determined by blocked randomization. Each block contained one exemplar from each category, which resulted in six blocks of 10 items (each block containing 8 items from experimental categories and 2 items from filler categories). The ordering of exemplars within blocks was determined randomly, except that the two filler exemplars in each of the first and last blocks were used to make primacy and recency buffers, respectively.

Retrieval practice booklets. To implement our main manipulation, we made two kinds of retrieval practice booklets. For competitive retrieval practice subjects, each page displayed a category and the first two letters of an item (e.g., *dogs co___*). In contrast, for noncompetitive retrieval practice subjects, pages displayed the first two letters of a category and a completed exemplar (e.g., *fr___ orange*). Aside from this variation, the booklets were identical in format. All the booklets tested three exemplars from each of four categories. Each of the 12 items was tested three times, according to an expanding schedule; on average, 3.5 items intervened between the first and the second practice test, and 6.5 items between the second and the third. No two items from a category were tested adjacently, and we avoided repeated sequences of particular test items. Tests of filler categories were used to make it easier to honor these constraints and to control for primacy and recency effects, yielding a booklet containing 48 test pages in total.

To ensure that every item appeared in every condition, we counterbalanced which categories were practiced and, also, which exemplars within a category were practiced (see Anderson et al., 1994, for details). This process yielded four types of retrieval-practice booklets. The distractor phase booklet included reasoning problems that contained no words used in the main experiment.

Test books. Test books contained nine categories—one filler, to acquaint subjects with the procedure, followed by eight critical categories. Categories were tested with one exemplar per test page, in six-item blocks, by cuing with the category and a single-letter stem (e.g., *dog c___*). To control for output interference, the average test positions of practiced and baseline categories were matched. The order of particular categories was also counterbalanced so that, across subjects, the position of every category was equated. Finally, the order of items within each category was counterbalanced: For half of the subjects, items a, b, and c were tested in the first half of a category test, and for the remaining subjects, in the second half. This control ensured that all the items contributed to test order and retrieval practice combinations (e.g., practiced–first, practiced–

second, related–first, related–second, etc.) equally. Crossing our item and category position counterbalancing yielded four test orders, which were made into four test books.

The four retrieval practice counterbalancing conditions were crossed with each test book, yielding 16 practice-book/test-book combinations.

Procedure

There were three phases in the experiment: study, retrieval practice, and a category-cued recall test. In the study phase, the subjects were told that they would see category–example pairs and that they should study each pair for 5 sec by relating the example to its category name.

In the retrieval practice phase, the subjects were randomly assigned to the competitive or the noncompetitive retrieval practice condition, which were run in separate groups. Within each condition, the subjects received one of four booklet versions, depending on the counterbalancing group (see the Materials section). In the competitive retrieval practice condition, the subjects were told that each page contained a category with the first two letters of a studied exemplar, which they were both to recall and to write down within 7 sec, along with the category name. They were warned that items would be tested several times and that they should try to write the correct item each time. In the noncompetitive retrieval practice condition, the subjects were given similar instructions, except that they were told that they would be recalling the category that went with the provided exemplar. After the retrieval practice phase, the subjects did a reasoning task for the 20-min retention interval.

In the final test phase, the subjects were randomly assigned to one of four tests. They were told that each test page contained a category and the first letter of an exemplar (e.g., *fruit o___*) and that their task was to recall the previously studied word that fit the stem. They were asked to write the response underneath a given category–stem pair and were given 7 sec to do so, at which point they were signaled to proceed.

RESULTS

All analyses were done with type of retrieval practice, retrieval practice counterbalancing, and test booklet counterbalancing as between-subjects factors.

Performance During the Retrieval Practice Phase

Success rates for the competitive retrieval practice task were quite high (M = 82.9%) and typical of previous studies using these materials (Anderson et al., 1994). Performance on the noncompetitive retrieval practice task was also high (M = 99.3%).

Final Recall Performance

Retrieval-induced forgetting. As is shown in Figure 1, those subjects who performed competitive retrieval practice suffered more retrieval-induced forgetting than did the subjects who performed noncompetitive retrieval practice, as is demonstrated by the interaction of inhibition (baseline − related) with type of retrieval practice [$F(1,48) = 6.43$, $MS_e = 1.27$, $p < .02$]. Indeed, whereas retrieval-induced forgetting was significant for competitive retrieval practice subjects [baseline − related = 68% − 60% = 8% impairment; $F(1,48) = 6.12$, $MS_e = 1.34$, $p < .02$], it was not for noncompetitive retrieval practice subjects [baseline − related = 64% − 67% = 3% facilita-

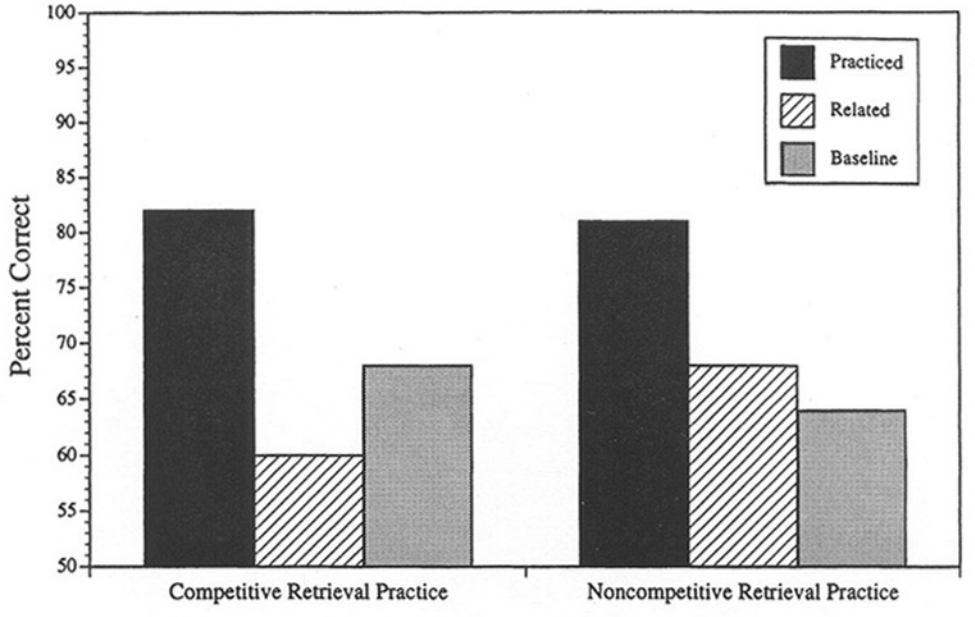

Figure 1. Percentage of items correctly recalled on a category-plus-stem cued-recall test as a function of retrieval practice status and type of retrieval practice. Practiced = items that were given retrieval practice; related = unpracticed members of practiced categories; baseline = unpracticed items from unpracticed categories. Competitive retrieval practice was a condition in which subjects were provided with the category and a two-letter stem as cues during retrieval practice (e.g., *fruit or* ___); Noncompetitive retrieval practice was a condition in which subjects were provided with the exemplar and a two-letter stem for the category as cues during retrieval practice (e.g., *fr___ orange*).

Table 1
Mean Percentage of Words Correctly Recalled as a Function of the Retrieval Practice Status of an Item, Type of Retrieval Practice, and Within-Category Testing Position

Type of Retrieval Practice	Retrieval Practice Status of an Item				
	Practiced	Related	Baseline	Inhibition	Facilitation
		Tested First			
Competitive	86	57	73	16	13
Noncompetitive	83	68	70	2	13
		Tested Second			
Competitive	78	64	63	−1	15
Noncompetitive	77	66	60	−6	17

tion; $F(1,48) = 1.18, p > .25$], supporting the hypothesis that retrieval-induced forgetting arises from the need to resolve competition during retrieval.

Testing position effects. Final recall performance for the subjects in our two retrieval practice groups is broken down by item type and testing position in Table 1. As can be seen in this table, final recall was better for items in the first half of a category test ($M = 72\%$) than for items tested in the second half [$M = 66\%$; $F(1,48) = 16.9$, $MS_e = 1.04, p < .001$], replicating prior work (Anderson et al., 1994; Anderson & McCulloch, 1999; Bäuml, 1998). Given this output interference, one might be concerned that the greater amount of inhibition in the competitive practice condition found in the overall recall analysis might reflect differences in output interference for our two types of practice. These concerns are not supported by the data, however. When only those items tested first in a category block are considered, the competitive practice condition again shows retrieval-induced forgetting [baseline − related = 73% − 57% = 16%; $F(1,48) = 13.30$, $MS_e = 1.41$, $p < .001$], but the noncompetitive condition does not (baseline − related = 70% − 68% = 2%; $F < 1$), and this interaction was significant [$F(1,48) = 6.20$, $MS_e = 1.41, p < .02$]. These findings show that differential output interference cannot explain the difference in impairment in the overall recall analysis and further replicate work showing that retrieval-induced forgetting is not produced by the prior recall of practiced items on the final test (Anderson et al., 1994).

One unexpected finding in our analysis by test postion was an elimination of retrieval-induced forgetting for the competitive retrieval practice condition when items were tested in the second category half (baseline − related = 63% − 64% = 1% facilitation; $F < 1$). This reduction in impairment contrasts with previous studies using this procedure, which have consistently found inhibition in both testing positions (e.g., Anderson et al., 1994; Anderson & McCulloch, 1999). The reasons for reduced impairment in this particular study are unclear. It is possible that impairment was reduced by integration effects, such as those documented in recent work on retrieval-induced forgetting (Anderson & McCulloch, 1999). Perhaps by recalling practiced items in the first testing positions, subjects accessed interexemplar retrieval routes that allowed them to offset the impairment for related items in the second testing positions. Consistent with this possibility, output interference for related items in both competitive and noncompetitive practice conditions was attenuated (7% facilitation and 2% impairment, respectively), relative to the output interference observed for other items in the experiment (8.5% impairment, overall).

Whatever factor reduced retrieval-induced forgetting in the second testing position, its effects appear not to alter the central finding of this study: greater retrieval-induced forgetting in the competitive than in the noncompetitive retrieval practice condition. This crucial interaction in impairment between the two forms of practice not only was significant in the overall analysis and in the analysis of the tested-first positions, but also did not vary reliably with testing position [$F(1,48) = 1.22$, $p = .28$].

Facilitation of practiced items. Retrieval practice caused the expected facilitation of practiced items. Importantly, the degree to which practiced item recall was facilitated over baseline recall (81% − 66% = 15%) was significant overall [$F(1,48) = 78.49, MS_e = .87, p < .0001$], and did not vary across the competitive (practiced − baseline = 82% − 68% = 14%) and noncompetitive (practiced − baseline = 80% − 64% = 16%) retrieval practice conditions ($F < 1$). The finding that practiced items can be significantly strengthened without impairing related items replicates previous work arguing against an interpretation of retrieval-induced forgetting in terms of strength-dependent competition (Anderson et al., 1994). Rather, the main factor determining retrieval-induced forgetting is the need to resolve competition during retrieval practice.

DISCUSSION

Previous work on retrieval-induced forgetting suggests an important role of the retrieval process in causing long-lasting forgetting. Although this previous work established retrieval as a behavioral determinant of forgetting, it left unclear whether this effect is specific to the selection processes that underlie retrieval of target information from memory. In the present experiment, this issue was examined and clear evidence for a recall-specific inhibition mechanism was provided. When the

subjects were provided with a category name along with a two-letter stem (e.g., *fruit or* ____) and were required to recall the to-be-practiced items, related exemplars were impaired on a delayed-recall test, as is typically observed. However, when the subjects were presented with the same to-be-practiced items and were asked to recall the category name (e.g., *fr___ orange*), delayed recall of related exemplars was unimpaired. Thus, although both groups received the same number of practice trials and gave exactly the same practice responses, related items were only impaired when the subjects actively had to recall the practice targets. These findings are compatible with the idea (Anderson et al., 1994; Anderson & Spellman, 1995) that inhibitory processes underlie retrieval-induced forgetting and, in particular, that these processes help to resolve interference during recall.

The present findings provide additional evidence against the idea that retrieval-induced forgetting reflects strength-dependent competition. That strengthening items during retrieval practice causes retrieval-induced forgetting is a plausible, even compelling, idea, but the evidence argues otherwise. Prior work on using the retrieval practice paradigm has shown, for example, that retrieval practice can facilitate the recall of practiced items by as much as 25% without impairing related items, provided that those items are low in taxonomic frequency and, therefore, less likely to interfere during retrieval practice (Anderson et al., 1994). The present findings extend that work by showing that even when the type of unpracticed competitor is held constant (high-frequency exemplars), significant strengthening of practiced items does not cause impairment if practice does not require the resolution of retrieval interference. Together with the findings of Bäuml (1996) concerning retroactive interference and those of Blaxton and Neely (1983) in the domain of semantic retrieval, the present findings thus argue for a special role of recall in the inhibition of related knowledge.

Although our findings favor the recall-specific inhibition view, it is reasonable to wonder whether the present differences in impairment might have been produced by undetected differences in strengthening across our two types of practice. More strengthening in the competitive practice condition might be expected, for instance, on the basis of work showing that retrieval practice facilitates later recall more than does simple reexposure of an item (e.g., Bjork, 1975; Carrier & Pashler, 1992; Gardiner et al., 1973). If competitive practice strengthened items more, related items might be more impaired, even if retrieval-induced forgetting is not recall specific. This hypothesis seems unlikely for several reasons. First, even if differences in strengthening went undetected by our final recall test, the substantial and statistically equivalent facilitation that did occur in the noncompetitive practice condition should have caused at least some impairment, but it did not. This lack of impairment seems unlikely if strengthening plays an important causal role in producing retrieval-induced forgetting. Furthermore, even given that competitive practice strengthened individual items more, the summed competition exerted by all of the competitively practiced items is not likely to be larger than that exerted by noncompetitively practiced items. The facilitation advantage found in studies comparing retrieval practice with extra exposures is often not dramatic (in the range of 4%–6%; see, e.g., Carrier & Pashler, 1992) and, in the present study, would be offset by the fact that fewer items were practiced successfully (and thus strengthened) in the competitive (83%) than in the noncompetitive practice condition (99%). Indeed, this difference can explain why we did not find the typical retrieval practice advantage during final recall. Taken together, these considerations suggest that recall-specific inhibition provides a more straightforward account of the data.

The present findings also demonstrate the importance of controlling recall order in studying the mechanisms of forgetting (Anderson et al., 1994; Bäuml, 1996, 1997). If recall order had not been controlled through the use of our category stem cued-recall procedure, it is possible that both forms of retrieval practice would have caused some impairment of unpracticed exemplars. This outcome is likely because both types of practice strengthen practiced items (as is shown in the present results), which makes it likely that those items will be recalled first on a final recall test in which recall order is left uncontrolled. Such biases in recall order for practiced items have the potential to cause test-based retrieval-induced forgetting (output interference), making it seem as though repeated presentation was sufficient to cause long-lasting impairment. By using a letter stem cued-recall procedure, we were able to compare unpracticed exemplars that were tested first in their category with comparable items in the baseline categories. Replicating Anderson et al. (1994), competitive retrieval practice caused significant retrieval-induced forgetting when output order was controlled. Under identical test conditions, however, repeated presentations of competing exemplars had little effect on the recall of related items. These findings strongly support the idea that retrieval-induced forgetting reflects the enduring effects of the earlier retrieval practice phase and not test-based competition from stronger practiced items (Anderson et al., 1994).

Our failure to find impairment in the noncompetitive retrieval practice condition may have implications for understanding the mechanisms underlying part–set cuing impairment. Research on part–set cuing has shown that giving subjects part of a previously studied category as a cue during a recall test impairs their ability to recall the remaining category members (Roediger, 1973; Rundus, 1973; Slamecka, 1972, 1975; see Anderson & Neely, 1996, Nickerson, 1984, and Roediger & Neely, 1982, for reviews). This finding is sometimes explained by assuming that cues become strengthened by their presentation on the final test, causing them to block recall of the re-

maining items (Rundus, 1973). However, several authors have provided evidence favoring an alternative interpretation in terms of strategy disruption (Basden & Basden, 1995; Sloman, Bower, & Roher, 1991). By this view, presenting part–set cues encourages a reorganization (or reinterpretation) of the items in the cue set, which diverts subjects from using the retrieval strategies they formed during the initial study phase. To the extent that the new organization conflicts with the earlier one, subjects receiving part–set cues may be at a disadvantage relative to uncued subjects. The present study suggests that strategy disruption may be a better explanation for the effects of part–set cues, inasmuch as the conditions thought necessary to induce blocking—the strengthening of cues—failed to cause impairment in our noncompetitive practice condition. Alternatively, part–set cuing may impair the noncue items indirectly, by leading subjects to recall the cues (overtly or covertly) earlier during the recall test. Thus, noncues may simply suffer more output interference when cues are presented (Karchmer & Winograd, 1971).

In conclusion, the present study shows that strengthening recently acquired information through repeated presentations is not sufficient to cause long-lasting forgetting of related knowledge. Rather, it is only when related knowledge interferes during an attempt to recall something else that it may be inhibited. If inhibitory processes are specifically tied to recall, it suggests a different perspective on why we sometimes feel limited in the amount of knowledge we can sustain in a highly accessible state. Inevitably, when we try to learn new items, such as names, numbers, or words, we assess our success at encoding the new knowledge by seeing whether or not we can recollect it—by administering self-tests (e.g., "What's his/her name again?"). Although such self-tests can be very effective at enhancing the retrieval of newly acquired information, that accessibility may come at the price of inhibiting other highly retrievable knowledge. Thus, it may not be the encoding of new student names but, rather, their retrieval that led David Starr Jordan to forget his fish.

REFERENCES

ALLEN, G. A., MAHLER, W. A., & ESTES, W. K. (1969). Effects of recall tests on long-term retention of paired associates. *Journal of Verbal Learning & Verbal Behavior*, **8**, 463-470.

ANDERSON, M. C., & BJORK, R. A. (1994). Mechanisms of inhibition in long-term memory: A new taxonomy. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 265-325). San Diego: Academic Press.

ANDERSON, M. C., BJORK, R. A., & BJORK, E. L. (1994). Remembering can cause forgetting: Retrieval dynamics in long-term memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **20**, 1063-1087.

ANDERSON, M. C., & MCCULLOCH, K. C. (1999). Integration as a general boundary condition on retrieval-induced forgetting. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **25**, 608-629.

ANDERSON, M. C., & NEELY, J. H. (1996). Interference and inhibition in memory retrieval. In E. L. Bjork & R. A. Bjork (Eds.), *Memory: Handbook of perception and cognition* (2nd ed.; pp. 237-313). San Diego: Academic Press.

ANDERSON, M. C., & SPELLMAN, B. A. (1995). On the status of inhibitory mechanisms in cognition: Memory retrieval as a model case. *Psychological Review*, **102**, 68-100.

ATKINSON, R. C., & JUOLA, J. F. (1974). Search and decision processes in recognition memory. In D. H. Krantz, R. C. Atkinson, R. D. Luce, & P. Suppes (Eds.), *Contemporary development in mathematical psychology: Learning, memory, and thinking* (pp. 243-293). New York: Freeman.

BADDELEY, A. D. (1982). Domains of recollection. *Psychological Review*, **89**, 708-729.

BARNES, J. M., & UNDERWOOD, B. J. (1959). "Fate" of first-list associations in transfer theory. *Journal of Experimental Psychology*, **58**, 95-105.

BASDEN, D. R., & BASDEN, B. H. (1995). Some tests of the strategy disruption interpretation of part–list cuing inhibition. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **21**, 1656-1669.

BATTIG, W. F., & MONTAGUE, W. E. (1969). Category norms for verbal items in 56 categories: A replication and extension of the Connecticut norms [Monograph]. *Journal of Experimental Psychology*, **80**, 1-46.

BÄUML, K.-H. (1996). Revisiting an old issue: Retroactive interference as a function of the degree of original and interpolated learning. *Psychonomic Bulletin & Review*, **3**, 380-384.

BÄUML, K.-H. (1997). The list-strength effect: Strength-dependent competition or suppression? *Psychonomic Bulletin & Review*, **4**, 260-264.

BÄUML, K.-H. (1998). Strong items get suppressed, weak items do not: The role of item strength in output interference. *Psychonomic Bulletin & Review*, **5**, 459-463.

BJORK, R. A. (1975). Retrieval as a memory modifier. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola symposium* (pp. 123-144). Hillsdale, NJ: Erlbaum.

BLAXTON, T. A., & NEELY, J. H. (1983). Inhibition from semantically related primes: Evidence of a category-specific inhibition. *Memory & Cognition*, **11**, 500-510.

BOUSFIELD, W. A., & BARCLAY, W. D. (1950). The relationship between order and frequency of occurrence of restricted associated responses. *Journal of Experimental Psychology*, **40**, 643-647.

CARRIER, M., & PASHLER, H. (1992). The influence of retrieval on retention. *Memory & Cognition*, **20**, 633-642.

CIRANNI, M. A., & SHIMAMURA, A. P. (1999). Retrieval-induced forgetting in episodic memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **25**, 1403-1414.

DAGENBACH, D., CARR, T. H., & BARNHARDT, T. M. (1990). Inhibitory semantic priming of lexical decisions due to failure to retrieve weakly activated codes. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **16**, 328-340.

DAPOLITO, F. J. (1966). *Proactive effects with independent retrieval of competing responses*. Unpublished doctoral dissertation, Indiana University.

GARDINER, J. M., CRAIK, F. I. M., & BLEASDALE, F. A. (1973). Retrieval difficulty and subsequent recall. *Memory & Cognition*, **1**, 213-216.

JACOBY, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory & Language*, **30**, 513-541.

JONES, G. V. (1989). Back to Woodworth: Role of interlopers in the tip-of-the-tongue phenomenon. *Memory & Cognition*, **17**, 69-76.

KARCHMER, M. A., & WINOGRAD, E. (1971). Effects of studying a subset of familiar items on recall of the remaining items: The John Brown effect. *Psychonomic Science*, **25**, 224-225.

KUČERA, H., & FRANCIS, W. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.

MANDLER, G. (1980). Recognizing: The judgment of previous occurrence. *Psychological Review*, **8**, 252-271.

MENSINK, G.-J. M., & RAAIJMAKERS, J. G. (1988). A model of interference and forgetting. *Psychological Review*, **95**, 434-455.

NICKERSON, R. S. (1984). Retrieval inhibition from part–set cuing: A persisting enigma in memory research. *Memory & Cognition*, **12**, 531-552.

POSTMAN, L. (1971). Transfer, interference and forgetting. In J. W. Kling & L. A. Riggs (Eds.), *Woodworth and Schlosberg's Experimental psychology* (3rd ed., pp. 1019-1132). New York: Holt, Rinehart & Winston.

REASON, J. T., & LUCAS, D. (1984). Using cognitive diaries to investigate naturally occurring memory blocks. In J. E. Harris & P. Morris

(Eds.), *Everyday memory actions and absent-mindedness* (pp. 53-70). London: Academic Press.

ROEDIGER, H. L., III (1973). Inhibition in recall from cueing with recall targets. *Journal of Verbal Learning & Verbal Behavior*, **12**, 644-657.

ROEDIGER, H. L., III (1974). Inhibiting effects of recall. *Memory & Cognition*, **2**, 261-269.

ROEDIGER, H. L., III, & NEELY, J. H. (1982). Retrieval blocks in episodic and semantic memory. *Canadian Journal of Psychology*, **36**, 213-242.

ROEDIGER, H. L., III, & SCHMIDT, S. R. (1980). Output interference in the recall of categorized and paired associate lists. *Journal of Experimental Psychology: Human Learning & Memory*, **6**, 91-105.

RUNDUS, D. (1973). Negative effects of using list items as recall cues. *Journal of Verbal Learning & Verbal Behavior*, **12**, 43-50.

SCHOOLER, J. W., FIORE, S. M., & BRANDIMONTE, M. A. (1997). At a loss from words: Verbal overshadowing of perceptual memories. *Psychology of Learning & Motivation*, **37**, 291-339.

SHAW, J. S., III, BJORK, R. A., & HANDAL, A. (1995). Retrieval-induced forgetting in an eyewitness-memory paradigm. *Psychonomic Bulletin & Review*, **2**, 249-253.

SLAMECKA, N. J. (1972). The question of associative growth in the learning of categorized materials. *Journal of Verbal Learning & Verbal Behavior*, **11**, 324-332.

SLAMECKA, N. J. (1975). Intralist cueing of recognition. *Journal of Verbal Learning & Verbal Behavior*, **14**, 630-637.

SLOMAN, S. A., BOWER, G. H., & ROHER, D. (1991). Congruency effects in part–list cuing inhibition. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **17**, 974-982.

SMITH, A. D. (1971). Output interference and organized recall from long-term memory. *Journal of Verbal Learning & Verbal Behavior*, **10**, 400-408.

SMITH, A. D. (1973). Input order and output interference in organized recall. *Journal of Experimental Psychology*, **100**, 147-150.

TULVING, E., & ARBUCKLE, T. Y. (1963). Sources of intratrial interference in paired-associate learning. *Journal of Verbal Learning & Verbal Behavior*, **1**, 321-334.

TULVING, E., & HASTIE, R. (1972). Inhibition effects of intralist repetition in free recall. *Journal of Experimental Psychology*, **92**, 297-304.

WIXTED, J. T., GHADISHA, H., & VERA, R. (1997). Recall latency following pure and mixed-strength lists: A direct test of the relative strength model of free recall. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **23**, 523-538.

WOODWORTH, R. S. (1938). *Experimental psychology*. New York: Henry Holt.

NOTE

1. Although the competitive and noncompetitive retrieval practice conditions were well matched in most respects, some differences were unavoidable. For instance, the retrieval practice cue format (e.g., *fruit or* __) arguably matched the final test cue format more in the competitive condition (e.g., *fruit o*___) than in the noncompetitive condition (e.g., *fr*___ *orange*). However, previous work has shown that a high degree of match between practice and test cues is not in itself sufficient to produce retrieval-induced forgetting (see Anderson et al., 1994, Experiments 2 and 3).

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