RETRIEVAL INDUCED FORGETTING IN

RECOGNITION MEMORY

by

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Retrieval Induced Forgetting in Recognition Memory

Abstract

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It has been demonstrated that the very act of remembering can itself cause forgetting of related information. This retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994) has been demonstrated in a variety of cued and free recall studies and has been attributed to an inhibitory mechanism activated during retrieval in order to deactivate the memory representations of competing items in order to facilitate correct recall of target items. The current study generalizes the effect of retrieval-induced forgetting to recognition memory. Experiment 1 demonstrated a typical retrieval-induced forgetting effect using a test of item recognition. Recognition performance was higher for practiced items than for control items from unpracticed categories, while recognition performance for the remaining items from practiced categories was lower than recognition performance seen for control items. Experiment 2 found a similar pattern in subjective remember responses when old recognition decisions were further discriminated by a remember/know test. The results from these two experiments support the active suppression explanation for retrieval-induced forgetting. Experiment 3 failed to support the competition assumption that is important in the active suppression hypothesis. The amount of retrieval-induced forgetting was not affected by the strength of competing items. In fact, no impairment was seen at all when item strength was

controlled. In addition, Experiment 4 failed to show evidence of retrieval-induced forgetting using an independent practice cue. Therefore, results from Experiments 3 and 4 may illustrate that the retrieval-induced forgetting mechanism operates differently in recognition than in free and cued recall.

Retrieval-induced Forgetting in Recognition Memory

Two features that are of primary importance to memory researchers are how information is retrieved from memory, i.e., remembering, and what happens when memory retrieval fails, i.e., forgetting. It is well-known that successful memory retrieval can serve to improve subsequent memory for the previously retrieved information (Allen, Mahler, & Estes, 1969; Carrier & Pashler, 1992; Gardiner, Craik, & Bleasdale, 1973; Gotts & Jacoby, 1974). One influential finding in the literature is that the act of remembering itself can cause interference with similar information and, therefore, result in forgetting of that information. Termed *retrieval-induced forgetting* (Anderson, Bjork, & Bjork, 1994), this phenomenon is thought to be driven by competition between two or more items in memory for a shared retrieval cue. Three topics that have created much debate are (1) whether the underlying cause for this retrieval-induced forgetting is simply a passive recovery failure caused by response competition between memory traces differing in activation strength or an active suppression process that is triggered by this competition, (2) whether the interference occurs at the level of the memory representations themselves or with their associative links to the shared cues, and (3) whether the resulting impairment decreases availability of the target item's memory representation or simply renders the item inaccessible for conscious retrieval. This study attempts to further investigate these important questions.

Interference Theory

Early research done in what is known as the "classical interference era" (1900 – 1970), developed a theory of forgetting based on interference caused by competition

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among responses for a shared stimulus at the time of retrieval (McGeoch, 1932). (Note that, since behaviorism was the dominant paradigm during this time period, early theories of forgetting were posited mainly in the framework of human learning theory, i.e. stimulus-response associations.) The main assumption in the response competition hypothesis of forgetting is that retrieval failures occur because other unwanted memories are retrieved instead of the target memories. When two different responses are learned to the same stimulus, one may block the other. Thus, two stimulus-response associations are learned independently, but one dominates at the time of retrieval (Crowder, 1976).

This basic hypothesis has been adopted into modern associative theories of interference. One main assumption of these associative theories is that retrieval of a target item occurs when a recall cue is sufficiently related to the target item so as to identify it uniquely in memory by its associative link. When a recall cue is linked to more than one item in memory, those other items compete with the target item for access to the shared cue. This has been referred to as the competition assumption (Anderson et al., 1994). The memory item that has the strongest associative link to the retrieval cue "wins" access to conscious memory. Successful memory retrieval is therefore based on the relative strengths of associative links between competing memory items and their retrieval cues. Consider a simple network model in which the category FRUIT is associated with two other memory representations ORANGE and BANANA with associative strengths of .5 and .3, respectively. Upon activation of the retrieval cue (in this instance the category FRUIT) the exemplars ORANGE and BANANA are going to be in competition for retrieval, but since ORANGE has the stronger association it will be more likely to be retrieved.

The second assumption of associative theories follows directly from the first assumption. Known as the strength-dependence assumption (Anderson et al., 1994), it assumes that when a retrieval cue is linked to more than one memory item, the likelihood of retrieving any specific item, given the shared retrieval cue, is determined by the absolute strength of the cue-target association relative to all other associative links to the shared retrieval cue. It follows that the amount of interference exerted by an item in memory increases in proportion to its memory strength, and the amount of interference due to competing items increases proportionally with the number of competing items (Anderson & Bjork, 1994; Anderson & Neely, 1996). This strength-based view of interference due to response competition has been the foundation of the retrieval mechanism described in many modern memory models (Gillund & Shiffrin, 1984; Mensink & Raaijmakers, 1988; Raaijmakers & Shiffrin, 1981; Rundus, 1973). These models hypothesize that the process of retrieval acts similarly to a ratio-rule equation, in which the probability of retrieval (as measured by conscious recall) may be illustrated as follows: p(recall target item A, given retrieval cue B) = Strength (B - A) / Strength (B - A)A) + Strength (B - C) + Strength (B - D)...Strength (B - Nth item), where C, D, ... N are competing items and B - A indicates the activation strength of the association between the retrieval cue B and the target item A. In other words, the likelihood of retrieving any target item given a certain retrieval cue is determined by the absolute strength of the cue-target association, relative to the strengths of all other associations between the same retrieval cue and competing items. Note that the denominator can become larger (thus decreasing the target item's probability for recall) either by increasing the number of items (e.g., the list length effect; Watkins & Gardiner, 1982) or

by increasing the associative strength of the items through repetition (e.g., the list strength effect; Ratcliff, Clark & Shiffrin, 1990).

The Paired-Associate Paradigm

Early studies of forgetting often incorporated verbal learning paradigms like the A - B, A - D paired-associates paradigm to demonstrate the basic associative strengthbased conditions of forgetting. This methodology was designed to provide control over the three aspects involved in response competition: the shared retrieval cues, the cuetarget association, and the relations between the cues and targets to other items in memory (Anderson & Neely, 1996; Crowder, 1976). As explained by classical interference theory, two different responses, B and D, are learned in association with the same stimulus, A. When the common stimulus recurs, the two previously-learned responses compete with each other for emission (Bower, 2000; Crowder, 1976). Although early verbal learning theorists often used any number of discrete units (e.g. nonsense syllables, words, or pictured objects) as stimuli, later researchers of the associative strength-based hypothesis of forgetting tended to use words as stimuli. Since the current study follows with this later methodology, the paired-associate task will be explained using words as the stimulus and response units. The basic paired-associate task involves the study of a list of unrelated A - B pairs of words (e.g. *cart - sun*) for a later memory test in which the first word (stimulus), denoted as A, will be given as a cue to retrieve the second word (response), denoted as B. The effects of response competition (interference) can be studied using this paradigm by having subjects subsequently learn a second paired-associate list before being asked to recall the items from the original list. This second, interpolated list may consist of word pairs that are totally unrelated to those used on the first list (an A - B, C - D list pairing), or it may consist of word pairs that are related to the target pairs in some way, for example, by sharing the same first word paired with a new second word (an A - B, A - D list pairing; see Anderson & Neely, 1996, for a description of these and other possible related pairings). The amount of interference can then be assessed as a function of this interpolated learning by examining the effect that learning the second list has on subsequent recall of the first list (or vice versa). Research using the paired-associate paradigm has provided a wealth of information regarding interference and its effects on retrieval; this introduction will focus on the effects of retroactive interference and its theoretical extensions, such as output interference and part-set cueing, as they are the most empirically similar to retrieval-induced forgetting and serve as good background for the associative strength-based explanations of retrieval-induced forgetting that will be discussed later.

Retroactive Interference

The first reported study demonstrating the effect of retroactive interference was conducted by Mueller and Pilzecker in 1900 (as described in Anderson, 2003), and since then a large number of studies have shown that performance in recalling a paired-associate list decreases, often severely, after learning a second paired-associate list, relative to a control condition in which no interpolated learning is required (Bower, 2000). Much of this retroactive interference can be explained by response competition. For example, when performance using A - B, A - D list pairings is compared to performance using A - B, C - D list pairings, recall performance for the A - B pairs is greatly reduced after learning an additional A - D paired-associate list relative to the condition in which an additional C - D list was learned. This is presumably because the

targets B and D share the same retrieval cue, A, in the first condition and are therefore in competition for the shared cue when it is presented later on a cued recall test (McGovern, 1964; Postman, 1962; Postman & Stark, 1969; also see Slamecka and Ceraso, 1960, for a discussion of early research on retroactive interference).

Theoretical Explanations for Retroactive Interference

Retrieval competition (occlusion). The most popular account for the impairment seen in retroactive interference studies has been degradation of the cue – target association caused by an occlusion process. According to such occlusion theories, the memory item that has the strongest associative link to the shared retrieval cue "wins" access to consciousness by blocking the associations to all competing memory items, making the retrieval cue ineffective for retrieving those items. In retroactive interference studies using the A - B, A - D list pairings, the fact that failure to retrieve B target items from the initial study list is often accompanied in a large number of studies by unwanted intrusions of corresponding D competing items from the second list seems to support this theory (Anderson, 2003; Anderson, & Bjork, 1994; Anderson & Neely, 1996; Crowder, 1976). The strengthening of the A - D associations, which corresponds to learning of the second list, is thought to lessen the effectiveness of the association between A and B target items; therefore, the D items obtain conscious awareness.

Unlearning. The unlearning hypothesis is particularly important in a discussion of retrieval-induced forgetting as it is the first interference theory to distinguish between the accessibility and the availability of a memory representation. As explained by an occlusion theory of retroactive interference, impairment on a memory test following the

acquisition of a second paired-associate list may be the result of response competition, but conflicting results have been found in studies of retroactive interference that are not adequately explained by an occlusion process. For example, if the interference caused by response competition is simply a passive byproduct of a relative strength-dependent retrieval process, then although the accessibility of certain memory items is blocked, their availability should remain intact. That is, competing items are rendered inaccessible to conscious awareness because the associations between those items and the shared retrieval cue are relatively weaker than the cue-target association; however, the absolute strength of these associations is not changed, therefore their availability remains intact. As a result, the number of second-list D intrusions would be expected to increase along with the amount of interference when the second-list A - D items are strengthened through retrieval practice. Contrary to prediction, however, the number of D intrusions has been shown to actually decrease as a function of learning trials on the second list while the amount of retroactive interference increases with increased strengthening of A - D list learning. This dissociation is not supported by an occlusion mechanism, but instead, Melton and Irwin (1940) argued for the existence of a separate mechanism that functions to actively inhibit the competing A – B associations by weakening the absolute strength of competing associations during learning of the second list. They referred to this active mechanism as an unlearning mechanism, as the initial A - B associations are "unlearned" (i.e. weakened) and replaced by A – D associations while learning the second list. Thus, B items are recalled less well on the final memory test because their association with A has been actively weakened during second list learning (Anderson & Neely, 1996; Postman, 1962). The unlearning hypothesis, therefore, assumes the

existence of an active inhibition mechanism that is activated by response competition to a shared retrieval cue.

Response-set suppression. An active unlearning mechanism working to lessen the effectiveness of associative retrieval routes may be an adequate explanation for the retroactive impairment seen in A - B, A - D list pairings that entails competition for a shared retrieval cue, but it does not adequately explain the presence of retroactive interference that has been shown in studies using A - B, C - D list pairings (McGovern, 1964; Postman, 1962; Postman & Stark, 1969). In this condition there is no overtly shared retrieval cue to compete with, as the retrieval practice that occurs in the learning of the C – D list consists of retrieval cues that were not present at all on the initial list. The additional associations being learned are essentially brand new, and should not compete at all with the associations formed in learning the initial lists. It would seem, then, that response competition need not be limited to competition between items on the basis of shared associations with a common retrieval cue but, instead, memory items themselves may be competing with each other for conscious awareness. Thus, the impairment being seen is the product of the active suppression of the entire first set of memory items in order to facilitate learning a second list of new items. Unlike occlusion and unlearning hypotheses, the response-set suppression hypothesis (Postman & Stark, 1969; Postman, Stark & Frasier, 1968) attributes retroactive interference not to a degradation of associative links but, rather, to a decrease in activation of the memory representations themselves to a level below that of conscious awareness. That is, although cue – target links remain intact (the items remain available), the decreased activation level renders the suppressed items inaccessible for retrieval. By actively

suppressing the entire first set of memory representations, it would be easier to learn a new set. The results of the suppression would be seen on a final recall test as retrieval impairment of the first list items as compared to retrieval performance for the second list items as well as evidence of intrusions from the most currently learned list which has not been suppressed. Note that the definition of response-set selection implies that it is episodic in nature, that is, the memory items that are suppressed as a class (all belong to the same episodic occurrence) rather than on the basis of individual cue-target associations, which may be preexisting semantic relationships as well as episodic associations. Thus, the response-set suppression hypothesis was the first theory of interference that addressed whether the effect of retroactive interference was semantic or episodic in origin, as earlier hypotheses such as occlusion and unlearning did not differentiate between these two forms of memory responses (Anderson & Neely, 1996).

Extensions of Retroactive Interference

Several more recent lines of research have extended the effects of retroactive interference beyond the paired-associate paradigm. The classical paired-associate paradigm used in early interference research consists of study episodes made up of repeated study-test trials, which were designed to ensure the participants were able to make the appropriate verbal response to the initial stimuli. In contrast, later interference research involved a study-test paradigm in which study items are presented only once, typically for a brief period of time, followed by a memory test for the studied items. Using this paradigm, studies have been able to demonstrate that the effect of retrieval impairment can be seen with even as few as one retrieval episode prior to the final memory test.

Output interference. One general finding of these studies is that recall performance decreased linearly as a function of an item's position on the memory test (Bäuml, 1998, 2002; Neely, Schmidt & Roediger, 1983; Roediger, 1973; Roediger & Schmidt, 1980; Smith, 1971; Tulving & Arbuckle, 1963, 1966). In a typical output interference paradigm, participants are presented with a study list of individual or pairedassociate items belonging to several different categories which is then followed by a category-cued recall test where they are given the category labels and asked to recall all members of the categories they can remember from the study list. Typical results from this paradigm include a dramatic decrease in the number of items recalled for categories that were cued later in the testing sequence. It would seem that retrieval of the initial category items on the memory test is interfering with the recall of later category items. Furthermore, this interference appears to be constrained only by testing position, as the amount of interference has been found to be independent of category positioning on the initial study list. Thus, impaired retrieval is the result of previous retrieval of other, competing items. Contrary to findings from previous interference studies, the retrieval interference seen in output interference studies is not linked to a shared retrieval cue. In this paradigm, the act of recall itself seems to be the cause of retrieval interference.

Part-set cueing. A second widely studied interference phenomenon is the part-set cueing effect (Slamecka, 1968). This refers to a decrease in performance in target recall when the retrieval cues used at test are drawn from the same category in memory as the target item. The study of part-set cueing is important because it extends the idea of retroactive interference caused by response competition to paradigms other than paired-associate recall. In the typical part-set cueing paradigm set forth by Slamecka (1968),

subjects learn several lists of words consisting of exemplars from a "set" group of five categories. These words were given singly in random order on the study list. Following the study list, subjects were asked to recall the words on the study list using retrieval cues for some of the items and not for others. What Slamecka found was that recall performance for the remaining non-cued items was significantly decreased when the retrieval cues were given, relative to recall performance when no cues were given at all. The key to the results found in this study is that the retrieval cues that were provided to subjects were from the same "set" (category) as the target items, and thus were in competition with the non-cued items for the shared "set" cue (Anderson & Neely, 1996; Rundus, 1973). More importantly, these set cues were not arbitrarily assigned to the target items as is the case in the paired-associate paradigm. In fact, part-set cueing has been found in a variety of conditions in which the studied list items can be either subjectively or intuitively organized into several different sets: for example, rhyming categories, semantic categories, or even experimental context for unrelated words (Roediger, 1978; Roediger, Stellon & Tulving, 1977; Mueller & Watkins, 1977).

Strength-Based Explanations for Retrieval Interference

Retroactive interference, output interference and part-set cueing can be adequately accounted for using the associative strength-based hypotheses described earlier, which emphasize the relative strength of associative links between targets and shared retrieval cues. For example, in both the paired-associate and part-set cueing paradigms, the probability of retrieving a target item ORANGE to a retrieval cue FRUIT is determined by the strength of the associative link between these two, divided by the associative strengths of all other competing items to the same retrieval cue, including the interpolated study items. In retroactive interference, the presentation of cue A, which is a shared cue with both previously studied items B and D, during the cued recall test causes B and D to be in competition with each other for retrieval during the test. The more strongly D is associated to A, therefore, the more interference it will incur (Anderson & Neely, 1996). Similarly, in part-set cueing, the presentation of an exemplar cue ORANGE (instead of FRUIT) strengthens the cue item's association with the shared set cue FRUIT, even though it has not been explicitly presented as a cue. At the same time, strengths of the non-cued associative connections between the set cue FRUIT and all other exemplars on the study list are diminished, resulting in response competition between the non-cued study items and the items used as retrieval cues for the remaining studied items.

Ratio-rule models further predict that increasing the number of competing items or increasing the associative strengths between the competing items and the shared retrieval cue will increase interference (by increasing the denominator of the ratio). Evidence supporting these further predictions has been seen in demonstrations of list-length effects in part-set cueing studies (increased impairment as a function of an increase in number of competitors in the study list; Gillund & Shiffrin, 1984; Roediger, 1973; Rundus, 1973; Slamecka, 1968, 1972; Watkins, 1975), as well as demonstrations of list-strength effects in retroactive interference studies (increased impairment caused by strengthening the A – B associations in the first study list; Melton & Irwin, 1940; Ratcliff et al., 1990).

In summary, early studies of interference have been important in developing the concept that the act of retrieval itself may be a significant cause of forgetting. The conflicting theoretical interpretations of the impairment caused by retrieval strengthening

using the paired-associate and part-set cueing paradigms, however, have shown these methods to be inadequate for fully testing the associative strength-based explanation of forgetting. The development of a new testing paradigm, known as the *retrieval-practice paradigm* (Anderson et al., 1994), was proposed to further test these hypotheses and further investigate the underlying mechanism of retrieval-induced forgetting.

The Retrieval-Practice Paradigm

Anderson et al. (1994), indicated several problems with both the associative strength-based hypotheses and the paradigms so far described that were being used to test them. In terms of the theory itself, which is based on the idea of spreading activation and supported by evidence from semantic priming studies, retrieval of some information should facilitate later retrieval of related information, not impair it (Neely, 1976; Warren, 1977). Studies of retrieval-induced interference, however, have demonstrated that prior retrievals can make subsequent recall of related information more difficult. Furthermore, this impairment is seen not only in episodic retrieval, as illustrated in the studies on retroactive interference and part-set cueing described previously, but in semantic retrieval as well (Blaxton & Neely, 1983; Brown, 1981; Brown, Whiteman, Cattoi, & Bradley, 1985). Several studies have demonstrated that speeded generation of several category exemplars (through cued-stem completion) slows the generation of later exemplars. For example, Blaxton & Neely (1983) found that subjects were slower to generate target exemplars from semantic memory after they had generated four other exemplars from the same category, as compared to performance from subjects that had to generate only one exemplar.

In terms of the paradigms being used to study this retrieval-induced forgetting, Anderson et al. (1994) pointed out that the retrieval strengthening component was confounded with either the initial study phase or with the test phase in previously used paradigms. In the paired-associate paradigm of retroactive interference participants learn a second list of associates paired with the same cue items as in the original list. This second set of associations is strengthened by repeated study-test trials prior to the final memory test. Thus, the retrieval strengthening occurs simultaneously with the learning of the second paired-associate list and is therefore confounded with the acquisition of the new competing items. Because of this confusion, it is difficult to determine whether the impairment of first list items on the final test is due to actual retrieval strengthening of the second list associations or, rather, response-set suppression of the first list items over the second list items (Postman et al., 1968). In the part-set cueing paradigm retrieval strengthening is thought to occur because some of the previously studied exemplars are presented as retrieval cues during the test, therefore strengthening those items over those that weren't presented as cues. In this way, however, the retrieval strengthening occurs simultaneously with the final test and therefore confounds the effects of retrieval strengthening with the effects caused by using the items as test cues (Basden, Basden & Galloway, 1977). The difficulty in separating the contributions of retrieval strengthening with other conditions in these two existing paradigms results in difficulty with theoretical interpretation, resulting in substantial disagreement, and so these methods do not provide a satisfactory means of testing the strength-dependent competition hypothesis.

In an attempt to resolve the confusion surrounding conflicting theoretical interpretations over the contributions of retrieval strengthening to the impairment of non-

strengthened items on a subsequent memory test, Anderson et al. (1994) developed a testing paradigm in which the three components involved in the effect of retrievalinduced forgetting are separated into three distinct phases in order to allow for a more systematic evaluation. In this way, the retrieval strengthening occurs in its own distinct phase and so is not confounded with either original learning or testing conditions. In addition, a retention interval was added before the final test and no items were presented as cues on the final recall test, therefore eliminating any effects caused by using studied items as test cues. Their ensuing retrieval-practice paradigm consisted of three distinct phases: an initial study phase, a retrieval-practice phase, and a final cued-recall test phase. In the study phase, subjects were given a series of category-exemplar pairs, such as FRUIT – ORANGE for study. Typically the study list included six members each from several different categories. The category label served as a shared cue for which exemplars competed for access during the later testing phase. Following the study phase, subjects entered the retrieval practice phase, in which they performed a word stemcompletion task given the category label and the first two letters of the target word (FRUIT - OR_____). This task served to induce retrieval practice for only half of the words from half of the categories (three items from each of four categories). Following the retrieval practice phase was a retention interval, typically lasting anywhere between two and twenty minutes. Finally, subjects were given a surprise category-cued recall test in which they were given the category label and asked to recall any exemplars they The influence of remembered having seen at any point during the experiment. interference resulting from the retrieval practice phase was assessed by contrasting recall performance on the final test between the two different types of items (i.e. practiced and

unpracticed items) from practiced categories with performance on the baseline items from the non-practiced categories.

Using a ratio-rule model to predict relative amounts of impairment across the three types of studied items, Anderson et al. (1994) predicted that recall performance on the final test would reflect the general strength of the three types of items. That is, the highest level of performance woul be for the practiced words from practiced categories, followed by unpracticed words from practiced categories, and then followed by unpracticed words from unpracticed categories (this group was considered the baseline condition because there was no strengthening involved with these items at all). Three results found in their study were counter to prediction, however. First, the expected increase in recall performance did occur for practiced items relative to the baseline items (25% more items were recalled); however, this increase in performance was accompanied by a decrement in performance on the unpracticed items from the practiced categories, as recall for these items was actually below that of baseline items (an 11% decrement). Second, it was found that the amount of impairment was seen only when the nonpracticed items consisted of strong category exemplars. No impairment at all was seen when weak category exemplars were used as unpracticed items. From this Anderson and his colleagues concluded that the impairment caused by the retrieval practice was not dependent on the relative strength of the practiced items, as would be predicted by strength-based accounts, but instead was dependent on the relative strength of the competing items, with the amount of impairment of an item determined by its tendency to interfere with the retrieval of practiced items. The facts that retention intervals of up to 20 minutes were used in the above-mentioned studies and that impairment is seen even

when output interference was controlled for by testing weak unpracticed competitors prior to testing stronger practiced competitors (Anderson & Bell, 2001; Anderson et al., 1994; Anderson, Bjork, & Bjork, 2000; Anderson & McCulloch, 1999; Bäuml, 2002; Bäuml & Hartinger, 2002) led Anderson et al. (1994) to propose a suppression-based retrieval mechanism. The basic assumption is that suppression of competing items is elicited during the retrieval practice phase because they interfere with retrieval of the target items. Suppression of these competing items leads to a greater probability of correct retrieval of the target items. The result of this suppression, however, is impaired recall of the suppressed items on the final memory test. Results from Anderson et al. (1994), as well as many other researchers have shown that the effects of suppression can be responsible for lasting episodic retrieval failure. It would follow from this that the effect of retrieval-induced forgetting is not simply brief, temporary associative strengthbased interference occurring within a single testing session.

Feature-Suppression Model of Retrieval-Induced Forgetting

Since the development of the retrieval practice paradigm, a large number of studies have shown evidence of retrieval-induced forgetting using various manipulations of the design. The results of these studies seem largely to illustrate that episodic retrieval does involve an inhibitory mechanism which has negative effects on the subsequent processing of related information. Anderson & Spellman (1995), attempted to specify this inhibitory mechanism in detail in their feature-suppression theory. Their theory assumes that memory representations are not discrete units but, rather, are distributed patterns of semantic features and the active mechanism involved in inhibition is a form of pattern suppression. In other words, memory items are represented as a network of

distributed semantic features that are shared with other memory items according to the degree of similarity between them. Since non-practiced items are similar to practiced items, there is some overlapping of shared features between practiced and non-practiced items. These feature units are activated when the feature is present in a target memory item or when it is activated by associated (overlapping) units. During retrieval practice, all (and only) features contained in a particular item's representation (as delineated by the study phase) are reactivated. Suppression is thought to occur during this practice phase because activation of overlapping features (those shared with the target item by similar competitors) results in response competition between the practice target and similar competitors for episodic retrieval. Because the selective nature of retrieval requires only the reactivation of target-specific features, a mechanism is needed to actively inhibit the features from competing memory items that would otherwise be reactivated along with the target-specific features. So, the process of retrieval practice therefore results in the activation of features associated with the target item and impairment of features corresponding to competing items. The suppression account emphasizes the importance of the retrieval process as an active part of the memory process, and not simply a byproduct of activation levels and a limited-capacity memory system as was inherent in early memory models. Later, Anderson (2003) would extend this argument by stating that the retrieval process serves as an executive control mechanism that serves to overcome internal interference from related information.

Role of item similarity. Findings from Anderson et al. (1994) demonstrated that the retrieval of target items from memory was not sufficient to cause impairment of unpracticed items, as impairment was seen only for competitors that were strong category

exemplars (Competitors that were weak exemplars remained relatively unaffected, even when significantly higher recall performance was shown for practiced items). Instead, impairment depended on whether competitors caused interference with the retrieval of the target. If the mechanism of retrieval-induced forgetting is based in the resolution of pattern competition from competing feature units as described by Anderson and Spellman (1995), it follows that item similarity should play a large role in the level of impairment seen, as it follows that similar items in memory should share a large number of common feature units. Results from Anderson & Spellman (1995) supported this idea, as the level of cross-category impairment seen in their study was related to the similarity of the competing items to the practiced items. They also found evidence of second-order impairment of items that were unrelated to the target item but highly similar to competing items. This would be expected from a feature suppression theory, as levels of impairment should reflect similarity relations, or the extent of feature overlap. As explained in Anderson and Spellman (1995), if non-practiced items from practiced categories are similar to practiced items in that 35% of their features overlap, then retrieval practice should cause those overlapping features to be highly active while suppressing the remaining 65% of features that do not overlap with the practiced items. If, however, a baseline item (non-practiced item from a non-practiced category) should happen to share 95% if its features with the inhibited portion of the unpracticed items then it, too would be inhibited from subsequent recall. According to this view, similarity is the impetus for response competition, which is the prerequisite for retrieval-induced forgetting. Other studies have also shown evidence that impairment hinges on item similarity (Anderson & McCulloch, 1999; Anderson, Green & McCulloch, 2000; Bäuml & Hartinger, 2002;

Smith & Hunt, 2000). For example, Bäuml & Hartinger (2002), found that retrieval practice caused impairment of items that were relatively dissimilar to the target items and no impairment for items that were highly similar to the practice targets. They divided category exemplars into similar and dissimilar subcategories and found impairment only if the competing item was from a dissimilar subcategory. That is, if LION was used as the practice target from the category ANIMAL, more impairment was seen for the unpracticed item HORSE than for the unpracticed item TIGER, which are both from the same category as the practiced item (ANIMAL) but were from different subcategories (HOOFED ANIMAL and PREDATORY ANIMAL). This was explained in terms of the feature suppression account because TIGER shares a larger percentage of overlapping features with LION relative to HORSE, and so a larger number of TIGER's features remained activated and less impairment occurred than for that of HORSE, which consisted largely of non-overlapping features that were suppressed, resulting in a larger amount of impairment.

Effects of semantic integration. Alternately, it has been found that the amount of impairment can be reduced, or even eliminated, by encouraging distinctive processing through semantic integration of the study list items by eliminating response competition between target items and competitors (Anderson & Bell, 2001; Anderson et al., 2000; Anderson & McCulloch, 1999; Macrae & Roseveare, 2002; Smith & Hunt, 2000). Essentially, response competition is caused in the retrieval-practice paradigm because the use of category – exemplar pairs on the study list encourages the processing of categorical similarities, which causes the activation of shared (overlapping) features and makes discriminating between items difficult in subsequent retrieval efforts. Smith and

Hunt (2000), however, emphasized distinctive processing by requiring subjects to make a difference judgment during the study list presentation, which resulted in the elimination of retrieval impairment. Theoretically, this study condition caused the activation of item-specific (non-overlapping) features, thus bypassing the suppression mechanism described above and eliminating impairment. Anderson and McCulloch (1999) encouraged semantic integration of the study items by asking subjects to study the list items by thinking of the other items that had already been presented in that category. The purpose of the study task was to establish an associative integration among category exemplars themselves, instead of only between each exemplar and the shared category cue, as is the result from the usual category-exemplar list presentation. Retrieval-induced forgetting was reduced in the semantic integration condition as compared to the normal instruction condition.

Location of impairment

Associative decrement. According to the active suppression account of retrievalinduced forgetting, unpracticed items are suppressed because they interfere with the retrieval of practice targets. However, the results listed so far do not indicate where in the memory network the suppression is active. Although incompatible with ratio-rule equation models, the fact that impairment depends on competitor strength could be explained by a strength-based unlearning theory. Perhaps the pattern of impairment seen reflects interference with the episodic associations between category labels and competing exemplars at the time of retrieval practice. According to unlearning theory, active suppression of individual target item representations would not be necessary in this explanation. One common theme in all non-inhibitory theories is that retrieval-induced forgetting should only occur for competing items that were studied and tested under the same shared retrieval cue.

Suppression of item representation. However, as seen by Anderson and Spellman (1995), the impairment from retrieval-induced forgetting as encountered in the retrieval practice paradigm appears to be cue-independent in nature; that is, the impairment generalizes to conditions where unrelated (independent) cues are used during the final test. This was established using an independent-probe method in which a different cue was used for retrieval during the final test than was used during the retrieval practice phase. According to the suppression hypothesis, suppression occurs at the level of the memory representation itself; therefore, it would be expected that impairment of competing items should be seen on the final test no matter what type of retrieval cue is used because it is the item itself, and not its association to the retrieval practice cue, that is the object of suppression. To test this, Anderson and Spellman (1995) modified the retrieval-practice paradigm to include exemplars that could be related to more than one category label. For example, two sets of category-exemplar pairs used in the study phase were RED - BLOOD, RED - TOMATO and FOOD - STRAWBERRY, FOOD -CRACKERS. It is important to note here that the exemplars TOMATO and STRAWBERRY, although studied with only one category label cue can actually be considered members of both categories based on pre-existing semantic relationships. Performance results from the final recall test showed evidence of cross-category impairment. That is, when practiced items (RED - BLOOD) were related to exemplars from non-practiced categories (FOOD - STRAWBERRY) impairment of the nonpracticed items (FOOD - STRAWBERRY) was seen on the final recall test. It was

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indicated that these items, because of their semantic similarity to competing items during the retrieval practice phase, must have been activated, and therefore suppressed, in order to allow for better chance at retrieval for the practice target items. Therefore, evidence of cue-independent impairment has been used to support the idea that the impairment seen in the retrieval-practice paradigm operates at the level of the item representation itself, and not with associative links between categories and exemplars. Further studies using novel cues during the final test have resulted in findings which indicate that cueindependence is a general property of the retrieval-induced forgetting effect (Anderson, 2003; Anderson & Bell, 2001; Anderson et al., 2000; Levy & Anderson, 2002; Saunders & MacLeod, 2006; Shivde & Anderson, 2001; however, see Perfect, Stark, Tree, Moulin, Ahmed, & Hutter, 2004, and Williams & Zacks, 2001 for arguments against cue independence).

Recall vs. Recognition

Theories based on strength-dependent response competition would predict that the effect of retrieval-induced forgetting would not occur on tests of recognition. That is, the effect is largely thought to be the result of a recall-specific mechanism in which competitors are blocked from conscious awareness (Anderson & Bell, 2001; Anderson et al., 2000; Anderson & Spellman, 1995; Blaxton & Neely, 1983; Bäuml, 2002; Ciranni & Shimamura, 1999); therefore, the presence of the specific items themselves during the recognition test would serve to overcome the negative effects of episodic retrieval blocking. Based on this argument, it has been suggested that the effects of retrieval-induced inhibition should be found only when using tests which do not use individual item-specific information as a cue for retrieval (Butler, Williams, Zacks, & Maki, 2001).

In support of this argument, evidence from other paradigms such as retroactive interference and part-set cueing has shown that strength-based interference effects (as measured in accuracy) do not typically generalize to recognition tests (Slamecka, 1975; Neely et al., 1983). This widely held opinion has theoretically precluded the use of recognition tests in the study of retrieval-induced forgetting.

While some studies have failed to show retrieval-induced forgetting in itemspecific memory tests such as category-plus-stem-cued recall, category-plus fragment cued recall, fragment-cued recall, and fragment completion (Butler et al., 2001; Perfect, Moulin, Conway & Perry, 2002; Williams & Zacks, 2001), some researchers have reported the presence of retrieval-induced forgetting in recall tasks using item-specific recall cues (Anderson & Bell, 2001; Anderson et al., 2000; Bäuml, 2002; Bäuml & Hartinger, 2002), in indirect memory tests (Bajo, Gómez-Ariza, Fernandez & Marful, 2006; Camp, Pecher, & Schmidt, 2005; Perfect et al., 2002; Veling & van Knippenberg, 2004) and even when recognition tests were used (Gómez-Ariza, Lechuga, & Pelegrina, 2005; Hicks & Starns, 2004; Spitzer & Bäuml, 2007; Starns & Hicks, 2004; Veling & Van Knippenberg, 2004; Verde, 2004). These results, although incompatible with the strength-dependent response competition explanation, are perfectly in line with active suppression theories which predict that impairment should be seen on any memory test aimed at accessing individual item representations. Other researchers, however, have not been able to find retrieval-induced forgetting effects when the final memory test is recognition (Koutstaal, Schacter, Johnson, & Galluccio, 1999).

Purpose of Current Study

Due to the lack of extensive research using recognition testing procedures, this study was designed to further investigate the role of retrieval-induced forgetting in the realm of recognition memory. Generalization of the retrieval-induced forgetting effect to recognition memory would provide useful evidence in support of an active suppression mechanism which serves to benefit the memory retrieval process. Evidence of the effect in both recognition and recall processes would be counter to several current theories mentioned previously that limit the effects of suppression to recall alone, and thus could be important in evaluating the retrieval mechanisms proposed in current theoretical models of memory.

The experiments in this study were designed to address three aspects of forgetting seen using the retrieval-practice paradigm which have been named to provide evidence for a suppression-based retrieval mechanism in memory. First, it has been assumed that impairment occurs at the memory representation itself, and not with associative links that may emanate from the memory representation to retrieval cues and/or other items in memory. A second assumption has been that the suppression mechanism serves to inhibit competing items from episodic retrieval by lowering their activation levels below the level required for conscious awareness. Third, it has been suggested that suppression is limited to items that may compete with the target item during retrieval practice.

Experiment 1 as designed to investigate the first of these assumptions, that the retrieval-induced forgetting effect reflects active suppression of the item representations themselves, and not simply associative decrement. Evidence of retrieval-induced forgetting in a recognition test would be difficult to explain in terms of inter-item

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associative response competition, as the item itself is presented during the test, which should eliminate any strength-based associative interference. Therefore, no evidence of retrieval-induced forgetting would be expected in studies of item recognition. If the item representation itself is suppressed, however, then evidence of this suppression would be predicted in both recall and recognition. Evidence of retrieval-induced forgetting in Experiment 1, therefore, would not only provide evidence extending the scope of retrieval-induced forgetting to the recognition arena, but this generalization to recognition would lend further evidence of active inhibition of the memory trace itself.

According to the active suppression hypothesis, the suppression mechanism acts by lowering the activation level of competing memory representations below the level required for conscious awareness; therefore, inhibition of a memory representation would preclude episodic recollection of that item. Experiment 2 investigated the constraint of episodic recollection on the retrieval-induced forgetting effect using a remember/know recognition task as the final memory test in a retrieval-practice paradigm. The remember/know procedure has been used as a way to subjectively measure a participant's state of episodic awareness during a recognition test. In addition to making a recognition decision, participants were asked to further designate each positive recognition decision as either a remember decision or a know decision. Remember judgments are thought to indicate a recognition decision based on a process of episodic recollection similar to that of recall, whereas know judgments are thought to reflect a recognition decision based on a more general sense of familiarity in the absence of actual recollection (Gardiner & Richardson-Klavehn, 2000). Since retrieval practice facilitates later retrieval of practiced items, these items should also be associated with a large number of remember responses.

If the process of suppression serves to lower the activation levels of competing items below that required for conscious awareness, then the suppressed items should elicit very few remember responses as compared to the non-practiced items that are not being suppressed.

Experiments 3 and 4 were designed to investigate the third assumption of retrieval-induced forgetting, which is that suppression is limited to items that may compete with the target item for a shared retrieval cue during retrieval practice. The goal of Experiment 3 was to directly compare the level of impairment seen when competitor strength was manipulated, while Experiment 4 was designed to investigate the competition assumption utilizing a modification of Anderson's original independent-cue technique. In Experiment 3, subjects practiced either all strong exemplars or all weak exemplars from the chosen practice categories. If suppression is dependent upon the amount of interference caused by competing items during retrieval practice, then a larger amount of retrieval-induced forgetting would be predicted when competitors consisted of strong category exemplars (i.e. when practiced items were weak) as compared to when competitors consisted of weak category exemplars (i.e. when practiced items were weak) as compared to when competitors consisted of weak category exemplars (i.e. when practiced items were weak) as compared to when competitors consisted of weak category exemplars (i.e. when practiced items were strong).

Experiment 4 utilized an independent retrieval cue during the practice phase in an attempt to circumvent the response competition proposed to give rise to retrieval-induced impairment of unpracticed competing items. If suppression is limited to items that may compete with the target item during retrieval practice, no evidence of retrieval-induced forgetting would be predicted if an independent cue was used during the practice phase. That is, if the retrieval cue MONKEY was used during the practice phase to elicit

retrieval of the target item BANANA, then it would not be expected to cause suppression of the other exemplars from the FRUIT category (such as APPLE or PEAR), as the cue MONKEY was not a commonly shared cue and therefore would not elicit any response competition, making suppression unnecessary.

Experiment 1

In order to investigate the effect of retrieval-induced forgetting in recognition, it must be established that the effect occurs with the present materials and experimental procedure. The first experiment was an attempt to replicate retrieval-induced forgetting effects found in recognition studies by other researchers (Gómez-Ariza et al., 2005; Hicks & Starns, 2004; Starns & Hicks, 2004; Veling & van Knippenberg, 2004). A retrieval practice paradigm similar to the original one used by Anderson et al. (1994), was used in Experiment 1, with the exceptions that the study list included individual exemplars (as typically used in studies of item recognition) rather than category-exemplar pairs and the final test was one of item recognition instead of cued recall. As mentioned previously, evidence of retrieval-induced inhibition in a recognition test would be predicted by the active suppression hypothesis, which posits that suppression reduces activation of the item representations for competing items during retrieval practice of related target items. Based on this hypothesis, it was predicted that any test which attempts to access suppressed items' memory representations would show evidence of impairment. Therefore, it was predicted that recognition hit rates would reflect the same empirical pattern as recall rates seen in previous studies. That is, it was expected that hit rates for practiced items would be significantly higher than hit rates for control items (unpracticed items from categories that were not practiced during the retrieval practice phase), while at
the same time it was expected that hit rates for unpracticed items from practiced categories would be significantly lower than hit rates for control items from unpracticed categories.

Method

Participants. Sixty-two students from introductory psychology classes participated to fulfill a class requirement.

Design. A standard retrieval practice paradigm was utilized, consisting of three main phases: a study phase, a retrieval practice phase, and a final test phase, with a distractor task separating the practice phase from the test phase. This design created three particular types of test items: practiced items from practiced categories (Rp+), non-practiced items from practiced categories (Rp-), and non-practiced items from non-practiced categories (Nrp). This results in a 2x3 repeated measures design, with factors including word status (old vs. new) and practice condition (Rp+, Rp-, and Nrp). The dependent variable measured was the number of positive ("yes") responses in a standard yes/no test of item recognition.

Materials. A full list of stimuli used can be found in the Appendix. Target stimuli consisted of twelve exemplars from eight common categories (ANIMAL, COLOR, FRUIT, FURNITURE, WEAPON, BODY PARTS, OCCUPATION, INSTRUMENT), plus four exemplars from three additional categories (FLOWER, CLOTHING, FABRIC) which were used as buffer/filler items and not tested. Category labels were chosen to be as unrelated to each other as possible. For example, both VEGETABLE and FRUIT were not used as categories because exemplars from both could be considered belonging to the related category FOOD. The words chosen for each

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category consisted of the twelve items with the largest response proportions for that category according to free association norms published by van Overschelde, Rawson and Dunlosky (2004). Items that contained the same first two letters as a previous list item in the same category were substituted with the next most qualified item in that category. Exemplars that could possibly fit into more than one category (e.g. ORANGE, which could be considered an exemplar for both the FRUIT and COLOR categories) were omitted and replaced in the same fashion.

Four of the eight categories were used for subsequent retrieval practice (designated Rp), while items from the remaining four categories did not receive additional retrieval practice (designated Nrp). The Rp categories were further divided into exemplars that were practiced (Rp+) and not practiced (Rp-). Item status (old/new) and retrieval practice status (Rp+, Rp-, Nrp) for each category and exemplar were counterbalanced, resulting in eight different study list/retrieval practice combinations.

Procedure. The study list consisted of 54 exemplars, divided into six exemplars from each of the eight target categories, plus two primacy/recency buffers from the three buffer categories that were not tested. (Note: Category names were not included in the presentation list.) The eight counterbalanced study list/retrieval practice combinations were presented to separate groups of participants. Each testing session consisted of a group of 15 - 20 students. Participants were seated in classroom style and all study and test items were projected onto a large screen in the front of the room. The study list was presented one word at a time and each word remained on the screen for 2 seconds. Participants were instructed to pay equal attention to each word as it appeared on the screen and were informed that a memory test for the study list would be given at the end

of the session.

Following the initial study phase, participants completed a retrieval practice phase consisting of a word stem completion task. Practice booklets contained twelve designated target items and three filler items (one item from each of the three buffer categories). A category name and the first two letters of a target exemplar (e.g., FRUIT – AP___) were printed in the center of each page and participants were instructed to complete the stem with a word that had been previously presented on the study list. The last three pages of the test booklet consisted of a distractor phase in which subjects completed a series of simple math problems. This task was designed to keep subjects occupied for a period of approximately five minutes.

When all participants had completed their test booklets, a memory test was presented on the projection screen one item at a time. The memory test consisted of a standard 96-item yes-no recognition test in which half of the items were old and half new. The initial order of test items was randomly determined, and the test items were given in the same presentation order on the recognition test for all groups. Because each group received different retrieval practice conditions the order of presentation of Rp+, Rp-, Nrp and new items on the recognition test was essentially counterbalanced between groups. This was done in order to control for effects of output interference. Each item on the test was presented on the same projection screen as the initial study list. The test items appeared one at a time, accompanied by the question "Did this item appear on the study list?" and remained on the screen for a duration of six seconds. Participants were given answer sheets and instructed to mark YES on the answer sheet if the test word had appeared previously on the study list and to mark NO if it had not appeared on the list. Following presentation of the last test item, all booklets and answer sheets were collected and the testing session ended.

Results

Hit and false-alarm rates are shown in Table 1. An alpha level of .05 was used as the standard of significance for all tests unless otherwise stated. A retrieval-induced forgetting effect was reflected in the pattern of recognition hit rates, which followed the order Rp+ > Nrp > Rp-. Retrieving items from a given category (Rp+) reduced the ability to recognize unpracticed words (Rp-) from the same practiced category during a later recognition test relative to baseline items (Nrp) from unpracticed categories.

Table 1

Mean proportion of positive recognition responses as a function of retrieval practice condition in Experiment 1.

	Item status			
	Old New			
	(hit rate)		(false-alarm rate)	
Retrieval practice condition		S.D.		S.D.
Rp+	.92	.13	.14	.13
Nrp	.79	.13	.17	.14
Rp-	.75	.19	.14	.13

Note: The false-alarm rates to new Rp+ and new Rp- items represent a common proportion ("yes" responses to new items from practiced categories)

Retrieval practice. In the retrieval practice phase, 87% of the items were correctly completed, indicating successful retrieval of target items.

ANOVA. An analysis of variance on numbers of positive responses found significant main effects of both item status (old vs. new), F(1, 61) = 502.89, MSe = 5.29, and practice condition, F(2,122) = 28.60, MSe = 0.19, as well as a significant interaction between these two factors, F(2,122) = 624.71, MSe = 18.57. The effect of practice condition was significant on both hits, F(2,122) = 46.55, MSe = 0.49, and false alarms, F(2,122) = 4.95, MSe = 1.73.

Hit rates. Mean performance in the test phase reflected a typical retrievalinduced forgetting effect for hit rates. That is, Rp+ items were recognized at higher proportion (92%) than Nrp (79%) items and Rp- items (75%), while Rp- items were recognized at a lower proportion than Nrp items and Rp+ items. Pairwise comparisons of hit rates confirmed the differences: The hit rate for Rp+ items was significantly different from the hit rates for both Nrp items [t(61) = 8.60] and Rp- items [t(61) = 7.91], and the hit rate for Rp- items was significantly different from the hit rate for Nrp items [t(61) = -2.01].

False-alarm rates. Because the false-alarm rates for Rp+ and Rp- items as presented in Table 1 represent a shared proportion, analyses of false-alarm rates were limited to differences in the proportions of "yes" responses made to new items from practiced categories and new items from unpracticed categories. Words from practiced categories showed lower false-alarm rates than those from non-practiced categories (14% and 17%, respectively). As with hit rates, a separate within-subjects ANOVA confirmed the overall difference, F(2,122) = 4.95, $MSe = 1.73^{-02}$. A pairwise comparison showed this 3% difference in false-alarms rates was significant [t(61) = 2.23].

Discussion

The results seen here reflect both a benefit of retrieval practice for practiced (Rp+) items and an impairment of related, non-practiced (Rp-) items in later recognition as compared to baseline (Nrp) words from non-practiced categories. Recognition hit rates showed the same empirical pattern as performance rates seen in recall studies. Therefore, the results of Experiment 1 extended the effects of retrieval-induced forgetting to a test of item recognition. As previously stated in the introduction to this study, evidence of retrieval-induced forgetting in a recognition test is unlikely to be explained by non-inhibitory theories, as the presence of the non-practiced studied items themselves on the recognition test should counteract any interference due to associative competition. Instead, the present results would appear to support an active suppression explanation of the retrieval-induced forgetting effect in which the memory representations themselves are affected, rather than the associative links between items and retrieval cues. Because suppression acts on the memory representations themselves, any attempt at accessing the suppressed item should result in retrieval impairment.

Experiment 2

Evidence from Experiment 1 provided evidence that the suppression induced by retrieval practice operates on the memory representations of competing items. It has been proposed that the purpose of the suppression mechanism at work here may be to block interfering items from conscious awareness in order to increase the probability for retrieval of the correct target items (Anderson & Bell, 2001; Anderson et al., 2000; Anderson & Spellman, 1995; Blaxton & Neely, 1983; Bäuml, 2002; Ciranni & Shimamura, 1999; Johansson, Aslan, Bäuml, Gäbel, & Mecklinger, 2006). Competing items are activated during the retrieval practice phase along with related target items, but are then suppressed to alleviate response competition.

According to the active suppression hypothesis, the suppression mechanism elicited by retrieval practice acts by lowering the activation level of competing memory representations below the level required for conscious awareness; therefore, inhibition of a memory representation would preclude episodic retrieval of that item. This makes sense in terms of performance on recall tasks, as episodic retrieval is required in order for the recall process to be successful. Evidence of retrieval-induced forgetting in a recognition task may initially seem to refute the argument that it is a recall-specific phenomenon, as the suppressed items themselves are presented during the recognition test and therefore cannot be blocked from conscious awareness; however, it is still possible that the suppression caused by retrieval practice is affecting episodic retrieval of the suppressed items. Researchers who promote a dual-process theory of recognition suggest the recognition decision itself may involve both a recall-like, episodic retrieval process and a familiarity-based decision process in the absence of episodic retrieval (Cary & Reder, 2003; Joordens & Hockley, 2000; Mandler, 1980; Yonelinas, 1994; see also Yonelinas, 2002, for an extensive review). One method developed to separate the effects of episodic recollection and familiarity in recognition decisions has been the remember/know paradigm (Tulving, 1985). In this procedure, subjects are asked to describe the qualitative nature of their recognition decisions when they classify a test item as old. They are asked to respond "Remember" when their decision is based on a recall-like (episodic) recollective experience, and to respond "Know" if their decision is based solely on familiarity (in the absence of any episodic recollective experience).

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Using this procedure, the proportion of remember responses can be used as a measure of episodic recollection. Although the theoretical interpretation of remember/know data is controversial (see, e.g., Donaldson, 1996; Dunn, 2004; Gardiner & Richardson-Klavehn, 2000), remember judgments have been shown to converge with other behavioral and physiological measures of recollection (Yonelinas, 2002).

In order to further investigate the constraint of episodic recollection in the retrieval-induced forgetting effect, Experiment 2 included a remember/know judgment with every positive recognition decision. If the levels of recognition performance across retrieval practice condition seen in the previous experiment were due to differing levels of episodic retrieval resulting from response suppression, then the proportions of remember responses in Experiment 2 should follow the same pattern across retrieval practice condition as overall hit rates. It was predicted that, in addition to Rp+ items showing more remember responses than Rp- and Nrp items as a result of strengthening of practiced items, Rp- items would show fewer remember responses than either Rp+ or Nrp items, as these items would require weakening in order to suppress them from conscious awareness and thus lessen the effects of response competition. It was also predicted that Nrp items would show an intermediate number of remember responses, as they were neither strengthened nor suppressed as a result of retrieval practice.

Method

Participants. Ninety-seven students from introductory psychology classes participated to fulfill a class requirement.

Design. The same 2x3 repeated measures design was used as for Experiment 1, with factors including word status (old vs. new) and practice condition (Rp+, Rp-, and

Nrp), with the exception that the dependent variable (the number of positive ("yes") responses) was further divided into two additional categories: Remember vs. Know.

Materials. The same materials were used as in Experiment 1.

Procedure. The study and retrieval practice phases were identical to those in Experiment 1. The final memory test consisted of a standard 96-item yes-no recognition test in which half of the items were old and half new. Participants were given answer sheets and instructed to mark YES on the answer sheet if the test word had appeared previously on the study list and to mark NO if it had not appeared on the list. In addition, for each YES response made during the recognition test, subjects were asked to circle REMEMBER if they explicitly remembered seeing the word on the list; or KNOW if they didn't explicitly remember seeing it on the list but it seemed very familiar, so they thought it must have been on the list. The definitions of Remember and Know responses were included in the test instructions, which followed closely to the standard instructions presented by Gardiner and Richardson-Klavehn (2000). Following presentation of the last test item, all answer sheets were collected and the testing session ended.

Results

Hit rates and false-alarm rates are shown in Table 2. Separate analyses of variance were conducted on the overall number of positive responses as well as the number of remember and know responses. As in Experiment 1, retrieving items from a given category (Rp+) reduced the ability to recognize unpracticed words (Rp-) from the same practiced category during a later recognition test relative to baseline items (Nrp) from unpracticed categories. In addition, the proportions of remember responses made as a function of practice condition reflected the same pattern as that of overall recognition

hit rates: Rp+ > Nrp > Rp-.

Retrieval practice. In the retrieval practice phase, 91% of the items were correctly completed, indicating successful retrieval of target items.

Overall recognition performance. An analysis of variance on numbers of positive responses found significant main effects of both item status (old vs. new), F(1,96) = 1658.65, MSe = 64.33, and practice condition, F(2,192) = 43.08, MSe = 0.34, as well as a significant interaction between these two factors, F(2,192) = 55.08, MSe = 0.37. The effect of practice condition was significant on hits, F(2,192) = 66.35, MSe = 0.71, but not false alarms, F(2,192) = 1.02, $MSe = 4.03^{-03}$.

Table 2

Mean Proportion of positive recognition responses and remember/know responses as a function of retrieval practice condition in Experiment 2.

	Item status			
Retrieval practice condition	Old (hit rate)		New (false-alarm	
			rate)	
<u>Overall</u>		S.D.		S.D.
Rp+	.93	.10	.17	.13
Nrp	.80	.13	.18	.13
Rp-	.77	.16	.17	.13
<u>Remember</u>				
Rp+	.79	.21	.05	.07
Nrp	.63	.20	.06	.08

Rp-	.61	.21	.05	.07
Know				
Rp+	.14	.18	.12	.11
Nrp	.17	.11	.13	.11
Rp-	.16	.12	.12	.11

Note: The false-alarm rates to new Rp+ and Rp- items represent a common proportion (yes responses to new items from practiced categories).

As in Experiment 1, evidence of retrieval-induced forgetting was reflected in the overall recognition hit-rate pattern. Rp+ items were recognized at higher proportion (93%) than Nrp (80%) items and Rp-items (77%), while Rp- items were recognized at a lower proportion than Nrp items and Rp+ items. Pairwise comparisons of hit rates confirmed the differences: the hit rate for Rp+ items was significantly different from hit rates for both Nrp items [t(96) = 9.79] and Rp- items [t(96) = 10.05]. The hit rate for Rp- items was also significantly different from the hit rate for Nrp items [t(96) = -2.06].

Analyses of false-alarm rates were again limited to differences in the proportions of "yes" responses made to new items from practiced categories and new items from unpracticed categories. Words from practiced categories showed lower false-alarm rates than those from non-practiced categories (17% and 18%, respectively), although this difference was not significant [t(96) = -1.01].

Remember responses. The mean proportions of remember responses are shown in Table 2. The pattern of remember responses is similar to the overall pattern of recognition hit rates in showing the retrieval-induced forgetting effect

(Rp+ > Nrp > Rp-). An analysis of variance on the number of remember responses found significant main effects for item status, F(1, 96) = 1136.72, MSe = 56.96, and practice

condition F(2,192) = 41.86, MSe = 0.48. A significant interaction was found between practice condition and item status, F(2,192) = 51.77, MSe = 0.52. The effect of practice condition was significant for both hits, F(2,192) = 52.04, MSe = 1.00, but not false alarms, F(2,192) = .92, $MSe = 2.15^{-03}$).

A larger proportion of remember responses were made to Rp+ items (79%) than to either Nrp items (63%) or Rp- items (61%). Pairwise comparisons of hit rates confirmed the differences: The hit rate for Rp+ items was significantly different from hit rates for both Nrp items [t(96) = 8.12] and Rp- items [t(96) = 8.94]. While fewer remember responses were made to Rp- items than to baseline Nrp items, this difference was not significant [t(96) = -1.09].

Differences in the number of remember responses made as a function of practice condition was seen for new items as well. Words from practiced categories showed lower rates of false remember responses than those from non-practiced categories (7% and 8%, respectively), although this difference was not significant, t(96) = -0.96.

Know responses. The mean proportions of know responses are shown in Table 2. A smaller proportion of know responses were made for Rp+ items (14%) than for either Nrp items or Rp- items (17% and 16%, respectively), while the proportion of Rp- items (16%) was smaller than that for Nrp items (17%). Neither of these differences was significant, however. Unlike in the remember responses, there was no significant main effect of practice condition or interaction between the factors of item status or practice condition. The only significant effect found was in the number of know responses as a function of practice condition for either old or new items, F(1,96) = 8.70, MSe = 0.18.

Discussion

The results for overall positive responses in this experiment replicate the pattern in hit rates found in Experiment 1. Hit rate proportions reflected both a benefit of retrieval practice for practiced (Rp+) items and an impairment of related, non-practiced (Rp-) items in later recognition as compared to baseline (Nrp) words from non-practiced categories. In addition, the same empirical pattern which was seen in the overall recognition hit rates was paralleled in the proportions of remember responses. Significantly more remember responses were made to Rp+ items than to Nrp and Rpitems. In addition, fewer remember responses were made to Rp- as opposed to Nrp items; unfortunately, this difference in hit rates was not significant. The results seem to indicate that participants may be more likely to qualitatively "remember" a practiced item was old, but less likely to "remember" a competing item as old, even if it was from a practiced category, but this cannot be considered conclusive evidence for suppression of competing memory traces. Therefore, Experiment 2 provided additional evidence that suppression of competing memory traces occurred, but did not conclusively support the hypothesis that the pattern reflected in overall recognition results is a result of the influence suppression has on conscious retrieval of practiced vs. non-practiced items.

Experiment 3

A third assumption of the active suppression hypothesis is the competition assumption. According to Anderson et al. (1994), although it is the retrieval process that elicits the suppression seen in retrieval-induced forgetting, retrieval of items from memory is not sufficient to produce the effect. Suppression is dependent upon the amount of interference posed by competing memory items. In a typical retrieval practice

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paradigm, the retrieval cue used during the practice phase (i.e. the category label) is shared among several studied items which are members of that category. When the shared retrieval cue is presented, items in memory that share a strong association with that cue are expected to cause a large amount of interference with retrieval for the target item; therefore, these items are suppressed in order to facilitate recall of the correct target item. Memory items that only have a weak association with the shared retrieval cue, however, would not be expected to create a large amount of interference if the target item has a sufficiently strong association with the practice cue. Suppression would not be required for these weaker memory items, so there should be no impairment of weak competitors on the final memory test.

To test this assumption, Anderson et al. (1994), manipulated the strength of the exemplars used in the retrieval-practice paradigm in order to investigate whether impairment would occur when studied and practiced categories consisted of all weak exemplars, all strong exemplars or mixed strong and weak exemplars. Their results showed evidence of retrieval-induced forgetting only when strong exemplars were studied and practiced and when weak items were studied and strong items were practiced. Thus, in accordance with their hypothesis, greater impairment was seen when non-practiced competitors were strong category exemplars. Furthermore, no significant difference in impairment of Rp- items was seen as a function of Rp+ item strength (Anderson et al., 1994, Experiment 3), further supporting the argument that the level of suppression elicited in the retrieval practice phase is dependent upon the amount of interference caused by competing items and not on the increased strength of practiced items themselves.

Since the competition assumption is one of the major arguments used in support of the active suppression hypothesis, and this study is aimed at demonstrating active suppression in a study of recognition, it is important to demonstrate evidence that the level of impairment seen in recognition is a function of the strength of non-practiced competing items. Therefore, Experiment 3 used the same manipulation of category composition as that used by Anderson et al. (1994), with the final memory test being one of item recognition instead of cued recall.

Method

Participants. One hundred ninety-two students from a variety of undergraduate psychology classes participated to fulfill a class requirement.

Design. The same 2x3 repeated measures design was used as in Experiment 1, with factors including word status (old vs. new) and practice condition (Rp+, Rp-, and Nrp). In addition, all categories used consisted of both strong and weak items, and category composition was manipulated between-subjects. Category composition was comprised of four levels, described as follows: Two pure conditions, SS and WW, in which only strong category exemplars or only weak category exemplars, respectively, were used in both the study and retrieval practice phases, and two mixed conditions, MS and MW, in which the study list contained both strong and weak exemplars and either strong items (in the MS condition) or weak items (in the MW condition) were used as target items in the retrieval practice phases. The dependent variable measured was the number of positive ("yes") responses in a standard yes/no test of item recognition.

Materials. The target categories used for this experiment were extended to accommodate all four category composition conditions. A complete list of stimuli used

in the experiment can be found in Appendix B. Target stimuli consisted of twenty four exemplars from the same eight common categories used in Experiment 1, plus four exemplars from three additional categories which were used as buffer/filler items. Each category consisted of the twelve items with the largest response proportions and twelve items with the smallest response proportions for that category, according to free association norms published by van Overschelde, Rawson and Dunlosky (2004). {Note: weak items had to be added arbitrarily by the experimenter due to lack of information in the normative data for the following categories: Colors} The average response proportion for strong items was 60%, and the average response proportion for weak items was 2%. As in Experiment 1, items that contained the same first two letters as a previous list item in the same category and exemplars that could possibly fit into more than one category were substituted with the next qualified item in that category. Counterbalancing for item status, category composition and retrieval practice condition resulted in sixteen different study list/retrieval practice combinations.

Procedure. Each study list consisted of 54 exemplars, divided into six exemplars from each of the eight target categories, plus two primacy/recency buffers from the three buffer categories that were not tested. (Note: Category names were not included in the presentation list.) The counterbalancing for category composition and item status resulted in four different study lists, which were presented to separate groups of participants, while the counterbalancing for retrieval practice combination resulted in four different retrieval practice conditions within each group. Each testing session consisted of a group of approximately 16-20 students. Presentation of the study phase, retrieval practice phase, distractor phase and final test phase of the experiment was

identical to the procedure used in Experiment 1.

Results

Hit rates and false-alarm rates for each condition is shown in Table 3. Separate analyses of variance were conducted on the overall number of positive responses for each of the four list/practice conditions.

Mixed List/Strong Practice Condition. In the retrieval practice phase, 87% of the items were correctly completed, indicating successful retrieval of target items. An

Table 3

Mean Proportion of positive recognition responses as a function of retrieval practice condition and category composition in Experiment 3.

	Item status			
Retrieval practice condition	Old (hit rate)		New (false-alarm	
			rate)	
Mixed List/Strong Practice		S.D.		S.D.
Rp+	.91	.11	.12	.09
Rp-	.78	.20	.12	.09
Nrp	.75	.16	.15	.12
Mixed List/Weak Practice				
Rp+	.90	.11	.15	.12
Rp-	.79	.14	.15	.12
Nrp	.78	.12	.16	.11
Strong List/Strong Practice				

Rp+	.92	.11	.06	.09
Rp-	.74	.19	.06	.09
Nrp	.75	.14	.09	.11
Weak List/Weak Practice				
Rp+	.88	.13	.19	.17
Rp-	.83	.14	.19	.17
Nrp	.80	.13	.19	.17

Note: The false alarm rates to new Rp+ and Rp- items represents a common proportion (yes responses to new items from practiced categories).

analysis of variance on numbers of positive responses found significant main effects of both item status (old vs. new), F(1, 41) = 644.92, MSe = 29.44, and practice condition, F(2,82) = 12.71, MSe = 0.13, as well as a significant interaction between these two factors, F(2,82) = 23.63, MSe = 0.21. The effect of practice condition was significant on both hits, F(2,82) = 20.93, MSe = 0.32, and false alarms, F(1,41) = 3.91, MSe = 0.01. Pairwise comparisons of hit rates confirmed the differences: The hit rate for Rp+ items was significantly different from hit rates for both Nrp items [t(41) = 5.74] and Rp- items [t(41) = 4.37]; however, the hit rate for Rp- items was not significantly different from the hit rate for Nrp items [t(41) = 1.43]. The difference in false-alarm rates between new items from practiced categories and new items from non-practiced categories was also significant [t(41) = 1.98].

Mixed List/Weak Practice Condition. In the retrieval practice phase, 72% of the items were correctly completed, indicating successful retrieval of target items. An analysis of variance on numbers of positive responses found significant main effects of

both item status (old vs. new), F(1, 39) = 1026.36, MSe = 27.17, and practice condition, F(2,78) = 14.05, MSe = 0.01, as well as a significant interaction between these two factors, F(2,78) = 15.26, MSe = 0.10. The effect of practice condition was significant on hits, F(2,78) = 20.80, MSe = 0.18, but not on false alarms, F(1,39) = 0.31. Pairwise comparisons of hit rates confirmed the differences: the hit rate for Rp+ items was significantly different from hit rates for both Nrp items [t(39) = 5.32] and Rp- items [t(39) = 5.50]; however, the hit rate for Rp- items was not significantly different from the hit rate for Nrp items [t(39) = 0.27]. The difference in false-alarm rates between new items from practiced categories and new items from non-practiced categories was not significant [t(39) = 0.56].

Pure Strong List/Strong Practice Condition. In the retrieval practice phase, 90% of the items were correctly completed, indicating successful retrieval of target items. An analysis of variance on numbers of positive responses found significant main effects of both item status (old vs. new), F(1, 55) = 1026.39, MSe = 45.46, and practice condition, F(2,110) = 42.96, MSe = 0.25, as well as a significant interaction between these two factors, F(2,110) = 43.62, MSe = 0.33. The effect of practice condition was significant on hits, F(2,110) = 51.02, MSe = 0.57, as well as on false alarms, F(1,55) = 5.54, MSe = 0.01. Pairwise comparisons of hit rates confirmed the differences: the hit rate for Rp+ items was significantly different from hit rate for Rp- items was not significantly different from the hit rate for Nrp items [t(55) = -0.42]. The difference in false-alarm rates between new items from practiced categories and new items from non-practiced categories was significant [t(55) = 2.35].

Pure Weak List/Weak Practice Condition. In the retrieval practice phase, 69% of the items were correctly completed, indicating successful retrieval of target items. An analysis of variance on numbers of positive responses found significant main effects of both item status (old vs. new), F(1, 53) = 584.94, MSe = 33.60, and practice condition, F(2,106) = 6.54, MSe = 0.01, as well as a significant interaction between these two factors, F(2,106) = 4.77, MSe = 0.01. The effect of practice condition was significant on hits, F(2,106) = 7.20, MSe = 0.01, but not on false alarms, F(1,53) = 0.33. Pairwise comparisons of hit rates confirmed the differences: the hit rate for Rp+ items was significantly different from hit rates for both Nrp items [t(53) = 4.12] and Rp- items [t(53) = 2.20]; however, the hit rate for Rp- items was not significantly different from the hit rate for Rp- items was not significantly different from the set for Nrp items [t(53) = 1.29]. The difference in false-alarm rates between new items from practiced categories and new items from non-practiced categories was not significant [t(53) = 0.58].

Discussion

If the competition assumption made by Anderson et al. (1994) held true for this experiment, then evidence of retrieval-induced forgetting should have been seen when strong competitors interfere with retrieval practice of the target item. That is, recognition performance for Rp- items should have been worse than recognition performance for Nrp items in the Strong List/Strong Practice and Mixed List/Weak Practice conditions. However, this was not found to be the case. Although there was evidence of retrievalinduced forgetting in the strong list/strong practice condition (which was the most similar to the list used in Experiment 1), this effect was not significant, and there was no evidence of retrieval-induced forgetting in any of the other three conditions. Increased performance for Rp+ items was seen in all four conditions, but proportions of hit rates for Rp- and Nrp items were not significantly different in any of the conditions.

In addition, if the level of impairment hinges only on the strength of the Rpitems, there should be no difference in levels of impairment of Rp- items seen between conditions where Rp+ items are strong and conditions where Rp+ items are weak. Again, this was not reflected in the data. Hit rates appeared to be similar across three out of the four conditions, differing only in the weak list/weak practice condition, where facilitation of the Rp+ items appears to be less than the other conditions, which also resulted in higher hit rates for Rp- and Nrp items than in the other conditions. This is very possibly the result of a lack of strengthening of Rp+ items due to worse performance in the retrieval practice phase, however.

The lack of findings in the results from Experiment 3 throw some doubt on the competition assumption made by Anderson and his colleagues in their explanation of the suppression effects of retrieval-induced forgetting. Although several other research studies have supported Anderson's assumption of competition dependence (Anderson, Green & McCulloch, 2000; Anderson & McCulloch, 1999; Anderson & Spellman, 1995; Bäuml & Hartinger, 2002; Smith & Hunt, 2000; Storm, Bjork & Bjork, 2007; Storm, Bjork, Bjork, & Nestojko, 2006), at least one other researcher has found evidence that does not support the competition-dependence assumption (Williams & Zacks, 2001). Of course, all of these prior studies have used recall tests in the final testing phase, while the current study utilized a recognition test. It is possible that the basis for suppression in recognition is somewhat different than the basis for suppression seen in recall studies. One explanation could be that the recognition decision is not based on conscious

recollection to the same extent as recall performance. Relative familiarity also plays a role in recognition decisions, and it is possible that the influence of familiarity has an additional effect on the suppression mechanism operating in retrieval-induced forgetting effects of recognition that has not been previously considered. This explanation would require further testing, however, which is beyond the scope of the current investigation.

Experiment 4

According to the active inhibition hypothesis, suppression occurs as a result of response competition for a shared retrieval cue which arises during the retrieval practice phase. Items that compete with the target item are suppressed during the practice phase in order to increase the probability of retrieval for the target item. Therefore, the impairment seen for those competing items on a later memory test is a residual effect of the suppression elicited by earlier retrieval during the practice session, and not a direct result of competition occurring during retrieval of items during the memory test. Consider that, in the standard retrieval-practice paradigm, items are presented during the study phase in category-exemplar pairs, practiced as category-stem completion pairs, and then tested using category labels as retrieval cues. Thus, in recall tests the category label is a common retrieval cue used in all three phases of the paradigm. If the retrievalinduced forgetting effect is the result of response competition to a shared retrieval cue, there is no way to effectively determine whether the suppression is occurring during the practice phase or during the testing phase. As mentioned previously, evidence from studies utilizing the independent-cue technique (Anderson & Spellman, 1995) appear to support the idea that the retrieval-induced forgetting effect is dependent upon response competition during retrieval practice. In these studies, impairment is seen for items from

the initial study list (Rp-) that were in competition with target items (Rp+) during the practice phase even when different, unrelated cues were used during the subsequent memory test (Anderson et al., 2000; Anderson & Spellman, 1995; Saunders & MacLeod, 2006). In essence, as long as the retrieval cues between the study phase and the practice phase match competition will ensue, resulting in suppression of competing, non-target items, and impairment will be seen during later testing. Because suppression is thought to act on the memory representation itself, impairment will be seen on a later memory test, whether or not a shared retrieval cue is used at test; therefore, any cue aimed at retrieving the representation of a suppressed item should be less effective. If the effect was caused by response competition during the testing phase, then impairment would not be expected when an independent cue is used for the final memory test, as there should be no competition during retrieval of the test item from other items because they were presented and practiced under the shared category label cue. The use of a recognition procedure, in which items are tested individually instead of with a retrieval cue, could be considered an additional form of independent-cue test (Starns & Hicks, 2004). That is, target items are practiced in the presence of a retrieval cue, but tested without a retrieval cue (i.e. there is no "shared" retrieval cue during the testing phase), so evidence of impairment using a recognition test, as in Experiment 1, can be considered new evidence of the cue-independent nature of the retrieval-induced forgetting effect. This evidence adds to a somewhat inconsistent body of literature in which some researchers have found evidence of cue-independent forgetting (Anderson, Green, & McCulloch, 2000; Anderson & Spellman, 1995; Johnson & Anderson, 2004; MacLeod & Saunders, 2005; Saunders & MacLeod, 2006) and others have not (Camp, Pecher, & Schmidt, 2007;

Perfect et al., 2004; Williams, & Zacks, 2001). Because of this conflicting evidence, it is important to investigate the cue-independence assumption further.

The current study attempted to investigate the cue-independence assumption using a modified independent-cue technique. According to the active suppression hypothesis, if the study items and practice items do not share a common retrieval cue, response competition would not be expected during the practice phase; therefore, there would be no need for suppression, and therefore no impairment would be seen on a subsequent memory test. This was investigated using an independent-probe method in which a cue unrelated to the category label FRUIT, such as MONKEY, was used as a practice cue to recall the target item BANANA. According to an active suppression hypothesis, if retrieval practice occurs in the form of FRUIT – BANANA, then any unpracticed target items that would strongly compete with BANANA for the cue FRUIT, which includes APPLE, would be suppressed during retrieval practice of BANANA and the result of this suppression would be evident in appearance of retrieval-induced forgetting on the final memory test. However, it was predicted that the item representation of APPLE would be accessible during the final recall test if an independent practice cue unrelated to FRUIT, like MONKEY, which was still sufficiently related to the item representation of BANANA to incur retrieval, was used during retrieval practice. Since APPLE would not interfere with the retrieval of BANANA to the cue MONKEY during retrieval practice, suppression would not be necessary, and no retrieval-induced forgetting would be evident on the final memory test.

Method

Participants. Thirty-six participants consisted of students from introductory psychology classes, who participated to fulfill a class requirement.

Design. The same 2x3 repeated measures design was used as in Experiment 1, with factors including word status (old vs. new) and practice condition (Rp+, Rp-, and Nrp). The dependent variable measured was the number of positive ("yes") responses in a standard yes/no test of item recognition.

Materials. The stimuli used during the presentation and testing phases were identical to those used in Experiment 1. The practice phase used independent cues instead of category labels to elicit retrieval of the target items. Independent cues were defined as cues that were unrelated to the shared category cue, but sufficiently related to the practice target item to elicit retrieval. For example, the study list contained the category FRUIT (although not explicitly stated) for which BANANA was used as an exemplar along with APPLE and CRANBERRY. For retrieval practice of the target item BANANA, an independent cue such as MONKEY was used instead of the category label FRUIT (used in Experiment 1). Independent cues were chosen according to normative data from Nelson, McEvoy, & Schreiber (1998; Appendix B). Cues were chosen according to strength of the forward association connection between the cue and the target (the probability that the cue will elicit retrieval of the target item). The item with the strongest forward connection was chosen unless that item could be confused as a member of another category, in which case the next strongest item was chosen. For the small number of target items that did not have normative data listed, an independent cue was arbitrarily assigned by the experimenter. A list of the independent cues used for this

experiment can be found in Appendix C.

Procedure. The current experiment used the same experimental procedure as used in Experiment 1 except that an independent cue was used instead of the category label during the retrieval practice phase in order to directly assess the effect of response competition in the practice phase.

Results

Hit and false-alarm rates are shown in Table 4. A retrieval-induced forgetting effect was reflected in the pattern of recognition hit rates, which followed the order Rp+ > Nrp > Rp-. Retrieving items from a given category (Rp+) reduced the ability to recognize unpracticed words (Rp-) from the same practiced category during a later recognition test relative to baseline items (Nrp) from unpracticed categories.

Table 4

Mean proportion of positive recognition responses as a function of retrieval practice condition in Experiment 4.

	Item status			
	Old New			
	(hit rate)		(false-alarm rate)	
Retrieval practice condition		S.D.		S.D.
Rp+	.94	.09	.16	.17
Nrp	.83	.12	.18	.15
Rp-	.76	.15	.16	.17

Note: The false-alarm rates to new Rp+ and new Rp- items represent a common proportion ("yes" responses to new items from practiced categories)

Retrieval practice. In the retrieval practice phase, 78% of the items were correctly completed, indicating successful retrieval of target items.

ANOVA. An analysis of variance on numbers of positive responses found significant main effects of both item status (old vs. new), F(1, 35) = 460.86, MSe = 24.62, and practice condition, F(2,70) = 18.30, MSe = 0.15, as well as a significant interaction between these two factors, F(2,70) = 23.71, MSe = 0.15. The effect of practice condition was significant on hits, F(2,70) = 30.67, MSe = 0.30, but not for false alarms, F(1,35) = 0.41.

Hit rates. Mean performance in the test phase reflected a typical retrievalinduced forgetting effect for hit rates. That is, Rp+ items were recognized at higher proportion (94%) than Nrp (83%) items and Rp- items (76%), while Rp- items were recognized at a lower proportion than Nrp items and Rp+ items. Pairwise comparisons of hit rates confirmed the differences: the hit rate for Rp+ items was significantly different from hit rates for both Nrp items [t(35) = 5.12] and Rp- items [t(35) = 7.17], and the hit rate for Rp- items was significantly different from the hit rate for Nrp items [t(61)= -3.14].

False-alarm rates. Words from practiced categories showed lower false-alarm rates than those from non-practiced categories (16% and 18%, respectively). A pairwise comparison showed this difference was not significant [t(35) = 0.64].

Discussion

If the retrieval cue MONKEY was used during the practice phase to elicit retrieval of the target item BANANA, then it would not be expected to cause suppression of the other exemplars from the FRUIT category, as the cue MONKEY is not a commonly shared cue. CRANBERRY and APPLE would not be expected to interfere with retrieval of the practice target item BANANA if MONKEY is used as the retrieval practice cue, so suppression would not be necessary. Therefore, if the retrieval-induced forgetting effect is the result of suppression occurring during the retrieval practice phase, there should be no evidence of retrieval-induced forgetting if an independent cue is used during the practice phase. However, Experiment 4 found clear evidence of retrievalinduced forgetting when independent cues were used for the retrieval practice phase. This goes against the competition assumption of Anderson et al.'s (1994) theory.

The evidence seen here draws into question the validity of the active suppression account of the impairment seen in studies of retrieval-induced forgetting, as the results can be explained in terms of non-inhibitory interference theory. As mentioned in the introduction, one common theme in all non-inhibitory explanations of retrieval-induced forgetting is that impairment should be seen when items are studied and tested under the same retrieval cue. This is because the competition responsible for causing retrieval interference is happening at the time of the final memory test, and not during retrieval practice. The results from Experiment 4 would appear to support this type of explanation.

It is possible, however, that the evidence of retrieval-induced forgetting seen in the current experiment is the result of covert cueing by the participants. During the retrieval practice phase it is possible that participants see the independent cue MONKEY, which elicits retrieval of the studied item BANANA. Along with this retrieval, participants may also remember that BANANA was one of the "fruits" that were on the study list. This would serve the same purpose as using the category cue itself as a

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retrieval cue; that is, covert cueing of the shared category cue would serve to activate the suppression mechanism, resulting in impairment on the final memory test.

General Discussion

Evidence of retrieval-induced forgetting was seen in three out of four experiments using an item recognition test in the final phase of the retrieval practice paradigm (Anderson et al., 1994). Recognition hit rates were higher for practiced items from practiced categories (Rp+ items) than for items from unpracticed categories, but this increase in performance for practiced items was accompanied by a decrement in performance for unpracticed items from these same practiced categories. Recognition performance for the unpracticed items (Rp- items) showed hit rates that were significantly lower than both practiced items and control items from unpracticed categories (Nrp items). The generalization of the retrieval-induced forgetting effect to recognition memory provides evidence in support of an active suppression explanation of the effect in which competing items are suppressed in order to increase the probability of retrieval of the correct target items. Interference-based effects, such as those seen in retroactive interference and part-set cueing, do not generalize to recognition memory, as the presentation of the studied items themselves during the memory test serves to release these items from episodic interference; therefore, a strength-based explanation of the results seen in this study would be inconsistent with the existing literature. However, the active suppression hypothesis predicts impairment on any test that attempts to access memory representations of the suppressed items, including recognition.

According to Anderson (1994, 2003), recollection is an active selection process which acts by lowering the activation levels of competing items below that of conscious

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awareness, thus precluding episodic recollection of those incorrect items. Results from this study seem to support Anderson's hypothesis, however, the evidence was inconclusive. This account assumes that the validity of a dual-process view of recognition, in which recognition can be based either on recollecting an experience (i.e. "remembering") or a sense of familiarity (i.e. "knowing"). Results from the remember/know task in Experiment 2 showed that the same pattern of overall recognition Participants were responses was suggested in the proportions of remember responses. more likely to qualitatively "remember" that a practiced item (Rp+) was old, reflecting the benefit of retrieval practice. In addition, participants were less likely to "remember" a competing item as old if it was from a practiced category (Rp-) as opposed to a control item from an unpracticed category (Nrp). This pattern would be predicted by the active suppression hypothesis, as competing items are less likely to be consciously recollected as a result of their memory representations being suppressed during the retrieval of target items. The results of the current studies are similar to those of another study investigating the effects of retrieval-induced forgetting in associative recognition (Verde, 2004; but see Spitzer & Bäuml, 2007, for conflicting results).

It is possible, however, to explain the results seen in this study as something other than suppression of episodic recollection as a result of response competition. There are single-process theories of recognition in which all responses are based on a unidimensional construct, such as familiarity or trace strength (see Ratcliff & McKoon, 2000, for a review). A single process approach to the current data might suggest that the distribution of hit rates and remember responses simply represents stronger memory traces (due to strengthening from retrieval practice) and a more conservative response criterion for remember responses (Donaldson, 1996; Hirshman & Masters, 1997). According to this view, recognition decisions are based on a single, familiarity-based process, and participants may adjust their response criterion along the underlying familiarity dimension by using a more conservative response criterion for stronger memory items. That is, upon encountering a test item which they did not remember having studied, participants may have considered whether the test item was a member of a previously practiced category prior to making a recognition decision, therefore creating a more conservative response criterion for unpracticed words that were related to practiced words and resulting in those words being recognized as old less often (i.e. "This word seems familiar, but I remember studying other words from this particular category, and I don't remember studying this word, so it must be new."). Furthermore, saying an item is both "old" and "remembered" may simply reflect a more conservative response strategy than saying an item is only "old," and is not necessarily evidence that episodic retrieval is occurring.

However, several studies have provided evidence that the criterion-shift explanation is unlikely in general, as participants do not seem to be aware of strength differences between test items and do not seem to use criterion shifts between trials in the same test (Morrel, Gaitan, & Wixted, 2002; Stretch & Wixted, 1998; Verde & Rotello, 2007; Wixted, 1992). Furthermore, researchers have found evidence of retrieval-induced forgetting (impairment of Rp- items) in recognition even when less conservative response criteria were made available to them (through source monitoring judgments) at the time of the memory test (Hicks & Starns, 2004) and when study items were associative and not categorical in nature (Starns & Hicks, 2004). Other researchers have argued that a strategic criterion shift for Rp- items should be reflected in terms of longer recognition response latencies, and this has not been found to be the case (Starns & Hicks, 2004; Veling & van Knippenberg, 2004). Therefore, the results from this study may be concluded as evidence in support of an active suppression hypothesis of impairment which is triggered by response competition and results in the deactivation of competing memory traces.

A second assumption inherent in Anderson's (1994, 2003) active suppression hypothesis is that the level of retrieval-induced forgetting is a function of the strength of competing items (Rp-). Because items that only share a weak association to a shared retrieval cue would not be expected to create a large amount of interference to more strongly-associated target items, less suppression (or no suppression at all) would be needed to prevent the recollection of these items during retrieval practice, and little or no impairment is predicted on the final memory test. Although some researchers have found evidence in support of the competition assumption in studies using free and cued recall (See Experiment 3, Discussion, for a review), the current study did not provide evidence that this assumption generalizes to studies of recognition. Experiment 3 showed no evidence of retrieval-induced forgetting when only strong or only weak items were used during the retrieval practice phase. Although hit rate proportions for practiced items (Rp+) were approximately the same whether all strong, all weak, or a combination of strong and weak items were studied, reflecting benefits of retrieval practice, hit rates for unpracticed items from the same practiced categories (Rp-) were not significantly different from those for control items from unpracticed categories (Nrp).

Results from Experiment 4 also question the competition assumption made by Anderson (1994, 2003) in support of an active suppression hypothesis of retrievalinduced forgetting. According to this hypothesis, suppression occurs as a result of items in memory competing for a shared retrieval cue during the retrieval practice phase. It follows from this hypothesis that if the retrieval cue used during the practice phase is an independent, rather than shared, cue, then competition would not ensue and suppression would not be necessary. However, Experiment 4 found evidence of retrieval-induced forgetting even with the use of independent cues during the retrieval practice phase. Unpracticed items from practiced categories continued to show evidence of impairment as opposed to control items from unpracticed categories. As stated earlier, however, any interpretation made based upon the results of this particular experiment should be considered carefully, as there is the possibility that participants were able to engage in covert cueing of the shared category labels during the retrieval practice phase even with the use of the independent cue. This covert cueing may have triggered suppression irrespective of the intended experimental design, and therefore may have influenced the results seen on the final memory test.

Because the competition assumption is one of the major arguments used to support an active suppression hypothesis of retrieval-induced forgetting, it is important to discuss why the results seen in this recognition study are inconsistent with results seen in recall studies. As mentioned previously, recognition decisions are based not only on conscious recollection (as is recall), but also are influenced by relative familiarity of the test items; therefore, recognition decisions may not be based on conscious recollection to the same extent as recall performance. Single- and dual-process theorists have argued extensively over the differential contributions made by recollective and familiarity-based retrieval processes in recall and recognition decisions (see Ratcliff & McKoon, 2000, for a review). Other variables, such as normative word frequency, have been shown to affect recognition and recall processes differently (Glanzer & Adams, 1985). Perhaps the impairment seen in retrieval-induced forgetting is another example of this type of dissociation. It is possible that the retrieval-induced forgetting effect is caused by a suppressive mechanism that is activated on a slightly different basis in recognition than in recall. Specifically, it is possible that an item's relative familiarity has an additional influence to that of episodic recollection in retrieval-induced forgetting effects of recognition. In any case, however, it is possible for a mechanism of this nature to affect recollection process differently in recall and recognition but still ultimately result in the reduction of general memory strength of the suppressed items. This, in turn, would result in impairment on a final memory test, whether that test was one of recall or recognition.

In conclusion, the study of retrieval-induced forgetting has important implications for human memory and learning. It is a robust effect that has been seen in a variety of settings, including fact learning (Anderson & Bell, 2001), eyewitness memory and misinformation effects (MacLeod, 2002; MacLeod & Saunders, 2005; Saunders & MacLeod, 2002; Shaw, Bjork & Handal, 1995), false memories (Bäuml & Kuhbandner, 2003; Starns & Hicks, 2004), social cognition (Dunn & Spellman, 2003; Macrae & MacLeod, 1999; Storm, Bjork & Bjork, 2005), and memory for autobiographical details (Barnier, Hung & Conway, 2004; Wessel & Hauer, 2006). Retrieval-induced forgetting has also been shown to facilitate future learning (Bjork & Bjork, 2003; Chan, McDermott, & Roediger, 2006; Storm, Bjork & Bjork, 2008), and individuals who show

a strong susceptibility to retrieval-induced forgetting tend to suffer a lower rate of cognitive failures in everyday life (Groome & Grant, 2005). All of this evidence seems to support the idea that forgetting is an adaptive process arising from the successful inhibition of unwanted information, rather than a simple failure of the memory system (Anderson, 2003), and that retrieval-induced forgetting might play a role in facilitating memory function by assisting selective retrieval.

Appendix A

Categories and Exemplars Used in Experiments 1 & 2

Target Categories:

ANIMAL	COLOR	FRUIT	<u>FURNITURE</u>
Dog	Blue	Apple	Chair
Cat	Red	Banana	Table
Horse	Yellow	Grape	Couch
Lion	Green	Pear	Bed
Bear	Purple	Strawberry	Desk
Tiger	White	Kiwi	Sofa
Cow	Pink	Pineapple	Dresser
Elephant	Brown	Watermelon	Loveseat
Deer	Indigo	Tomato	Lamp
Mouse	Magenta	Mango	Nightstand
Pig	Turquoise	Cherry	Ottoman
Rat	Teal	Lemon	Recliner
WEAPON	BODY PARTS	OCCUPATION	INSTRUMENT
WEAPON Gun	BODY PARTS Leg	OCCUPATION Doctor	INSTRUMENT Drum
WEAPON Gun Knife	BODY PARTS Leg Arm	OCCUPATION Doctor Teacher	INSTRUMENT Drum Guitar
WEAPON Gun Knife Sword	BODY PARTS Leg Arm Foot	OCCUPATION Doctor Teacher Lawyer	INSTRUMENT Drum Guitar Flute
WEAPON Gun Knife Sword Bomb	BODY PARTS Leg Arm Foot Finger	OCCUPATION Doctor Teacher Lawyer Nurse	INSTRUMENT Drum Guitar Flute Piano
WEAPON Gun Knife Sword Bomb Rifle	BODY PARTS Leg Arm Foot Finger Head	OCCUPATION Doctor Teacher Lawyer Nurse Firefighter	INSTRUMENT Drum Guitar Flute Piano Trumpet
WEAPON Gun Knife Sword Bomb Rifle Rope	BODY PARTS Leg Arm Foot Finger Head Hand	OCCUPATION Doctor Teacher Lawyer Nurse Firefighter Professor	INSTRUMENT Drum Guitar Flute Piano Trumpet Clarinet
WEAPON Gun Knife Sword Bomb Rifle Rope Mace	BODY PARTS Leg Arm Foot Finger Head Hand Ear	OCCUPATION Doctor Teacher Lawyer Nurse Firefighter Professor Accountant	INSTRUMENT Drum Guitar Flute Piano Trumpet Clarinet Saxophone
WEAPON Gun Knife Sword Bomb Rifle Rope Mace Axe	BODY PARTS Leg Arm Foot Finger Head Hand Ear Knee	OCCUPATION Doctor Teacher Lawyer Nurse Firefighter Professor Accountant Psychologist	INSTRUMENT Drum Guitar Flute Piano Trumpet Clarinet Saxophone Violin
WEAPON Gun Knife Sword Bomb Rifle Rope Mace Axe Grenade	BODY PARTS Leg Arm Foot Finger Head Hand Ear Knee Neck	OCCUPATION Doctor Teacher Lawyer Nurse Firefighter Professor Accountant Psychologist Dentist	INSTRUMENT Drum Guitar Flute Piano Trumpet Clarinet Saxophone Violin Tuba
WEAPON Gun Knife Sword Bomb Rifle Rope Mace Axe Grenade Missile	BODY PARTS Leg Arm Foot Finger Head Hand Ear Knee Neck Elbow	OCCUPATION Doctor Teacher Lawyer Nurse Firefighter Professor Accountant Psychologist Dentist Engineer	INSTRUMENT Drum Guitar Flute Piano Trumpet Clarinet Saxophone Violin Tuba Cello
WEAPON Gun Knife Sword Bomb Rifle Rope Mace Axe Grenade Missile Pistol	BODY PARTS Leg Arm Foot Finger Head Hand Ear Knee Neck Elbow Shoulder	OCCUPATION Doctor Teacher Lawyer Nurse Firefighter Professor Accountant Psychologist Dentist Engineer Secretary	INSTRUMENT Drum Guitar Flute Piano Trumpet Clarinet Saxophone Violin Tuba Cello Oboe
WEAPON Gun Knife Sword Bomb Rifle Rope Mace Axe Grenade Missile Pistol Club	BODY PARTS Leg Arm Foot Finger Head Hand Ear Knee Neck Elbow Shoulder Ankle	OCCUPATION Doctor Teacher Lawyer Nurse Firefighter Professor Accountant Psychologist Dentist Engineer Secretary Manager	INSTRUMENT Drum Guitar Flute Piano Trumpet Clarinet Saxophone Violin Tuba Cello Oboe Harp

Buffer/Filler Categories:

FLOWER	<u>CLOTHING</u>	FABRIC
Daisy	Shirt	Cotton
Tulip	Pants	Silk
Lily	Socks	Wool
Carnation	Underwear	Polyester
Appendix B

Strong and Weak Exemplars Used in Experiment 3

Target Categories:

ANIMAL	COLOR	<u>FRUIT</u>	<u>FURNITURE</u>
Strong:	Strong:	Strong:	Strong:
Dog	Blue	Apple	Chair
Cat	Red	Banana	Table
Horse	Yellow	Grape	Couch
Lion	Green	Pear	Bed
Bear	Purple	Strawberry	Desk
Tiger	White	Kiwi	Sofa
Weak:	Weak:	Weak:	Weak:
Skunk	Periwinkle	Pomegranate	Pillow
Possum	Beige	Coconut	Mirror
Panda	Burgundy	Guava	Hutch
Mule	Navy	Cranberry	Closet
Hyena	Aqua	Blackberry	Bureau
Gazelle	Tan	Honeydew	Rug
<u>WEAPON</u>	BODY PARTS	OCCUPATION	INSTRUMENT
Strong:	Strong:	Strong:	Strong:
Gun	Leg	Doctor	Drum
Knife	Arm	Teacher	Guitar
Sword	Foot	Lawyer	Flute
Bomb	Finger	Nurse	Piano
Rifle	Head	Firefighter	Trumpet
Rope	Hand	Professor	Clarinet
Weak:	Weak:	Weak:	Weak:
Wrench	Waist	Surgeon	Timpani
Taser	Heel	Pilot	Mandolin
Switchblade	Vein	Physician	Bongo
Razor	Throat	Mailman	Bell
Poison	Skin	Electrician	Accordian
Pipe	Spine	Designer	Xylophone

Buffer/Filler Categories:

<u>FLOWER</u>	<u>CLOTHING</u>	FABRIC
Daisy	Shirt	Cotton
Tulip	Pants	Silk
Lily	Socks	Wool
Carnation	Underwear	Polyester

Appendix C

Independent Cues Used in Experiment 4

Target Categories:

ANIMAL

Exemplar / Cue: Dog / Hound Cat / Meow Horse / Saddle Lion / Roar Bear / Grizzly Tiger / Leopard Cow / Moo Elephant / Tusk Deer / Doe Mouse / Squeak Pig / Hog Rat / Rodent

WEAPON

Exemplar / Cue: Gun / Trigger Knife / Dagger Sword / Pirate Bomb / Atomic Rifle / Assault Rope / Knot Mace / Spray Axe / Hatchet Grenade / Explode Missile / Patriot Pistol / Range Club / Member

Exemplar / Cue: Blue / Sky Red / Stoplight Yellow / Mellow Green / Plants Purple / Violet White / Black Pink / Panther Brown / Brunette Indigo / Ink Magenta / Paint Turquoise / Stone Teal / Duck

COLOR

BODY PARTS

Exemplar / Cue: Leg / Cramp Arm / Sleeve Foot / Inch Finger / Ring Head / Hat Hand / Glove Ear / Lobe Knee / Bent Neck / Giraffe Elbow / Joint Shoulder / Chip Ankle / Sprain

Buffer/Filler Categories:

FLOWER

Exemplar / Cue: Daisy / Miss Tulip / Bulb Lily / Pond Carnation / Lapel

<u>CLOTHING</u>

Exemplar / Cue: Shirt / Collar Pants / Zipper Socks / Sole Underwear

FRUIT

Exemplar / Cue: Apple / Core Banana / Bunch Grape / Vine Pear / Prickly Strawberry/Shortcake Kiwi / Fuzz Pineapple / Tropical Watermelon / Rind Tomato / Lettuce Mango / Chutney Cherry / Pie Lemon / Sour

OCCUPATION

Exemplar / Cue: Doctor / Stethoscope Teacher / Faculty Lawyer / Legal Nurse / Uniform Firefighter / Rescue Professor / Expert Accountant / Numbers Psychologist / Therapy Dentist / Cavity Engineer/Mechanical Secretary / Office Manager / Assistant

FURNITURE

Exemplar / Cue: Chair / Seat Table / Picnic Couch / Relax Bed / Mattress Desk / Office Sofa / Pillow Dresser / Drawer Loveseat / Snuggle Lamp / Lava Nightstand / Clock Ottoman / Footrest Recliner / Lazy

INSTRUMENT

Exemplar / Cue: Drum / Beat Guitar / Bass Flute / Piper Piano / Keyboard Trumpet / Brass Clarinet / Woodwind Saxophone / Tenor Violin / Orchestra Tuba / March Cello / String Oboe / Reed Harp / Heaven

FABRIC

Exemplar / Cue: Cotton / Swabs Silk / Satin Wool / Yarn Polyester / Synthetic

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