Retrieval Inhibition in Episodic Recall: Effects on Feature Binding

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1 Introduction

1.1 Benefits and costs of episodic processing

Many types of episodic processing show a mixture of induced benefits and costs, increasing later recall of the processed material and reducing recall of the unprocessed material. One such prominent class of cases is the strengthening of episodic material, whereby the binding between items and their cue(s) and/or the binding of intraitem features is enhanced. Results from a large body of research have shown that recall of learned material can be largely improved if the number of study trials, or study time, of the to-be-learned material is increased (Roberts, 1972). Such benefits of enhancing the binding level of episodic material, however, can be accompanied by costs if only part of the material is strengthened. In fact, if study time or study trials are increased for only a subset of the learned material, then such strengthening will increase recall for the strengthened material but lower recall for the nonstrengthened one (Ratcliff, Clark, & Shiffrin, 1990; Tulving & Hastie, 1972).

A similar picture arises if an increase in binding level occurs through repeated retrieval. Prior work has demonstrated that the retrieval of learned material improves later recall of the retrieved material (Hogan & Kintsch, 1971). Again, however, such benefits can be accompanied by costs if only part of the material is practiced. If subjects repeatedly retrieve a subset of previously learned material, then later recall of the nonretrieved material is worse than in a control condition in which no retrieval practice takes place at all (Anderson, Bjork, & Bjork, 1994; Anderson & Spellman, 1995). Obviously, enhancing the cue-item or intraitem binding, be it through relearning or retrieval, is not only beneficial for episodic recall but can be detrimental as well.

It might appear that cuing represents a special form of episodic processing insofar as cuing can only be beneficial for recall but not detrimental, thus constrasting in its effects with the mixture of benefits and costs which is caused by the strengthening of episodes. Indeed, cuing has been found to facilitate recall in many situations. For instance, if a categorized list with several items from each category is presented to participants and, at test, the category names are provided as retrieval cues, then such cuing typically improves recall performance compared to unaided free recall (Tulving & Pearlstone, 1966; see Tulving, 1974, for further examples).

However, cuing is not always facilitatory. If participants learn a categorized list and, at test, receive the category names of half of the learned categories as retrieval cues, then such part-list cuing improves recall of items from the cued categories but impairs recall of items from the uncued categories (Roediger, 1978). Detrimental effects of cuing occur also within subjective units. If subjects learn a categorized list and, at test, receive the category name plus a subset of the category's items as retrieval cues, then recall of the remaining category exemplars is lower than recall of the same items if only the category name is provided as a retrieval cue (Slamecka, 1968; Roediger, 1973). Obviously, just like the strengthening of episodes, cuing is beneficial in some cases, but detrimental in others (see Nickerson, 1984, and Roediger & Neely, 1982, for reviews).

** Figure 1 about here **

1.2 Mechanisms underlying the detrimental effects of strengthening and cuing

A simple account of the detrimental effects of strengthening and cuing is provided by the concept of *strength-dependent competition.* According to this concept, memories bound to a common cue (e. g., *FRUIT-apple*, *FRUIT-orange*) compete for renewed binding when that cue is presented. Corresponding evidence has been provided by a number of studies in which it was shown that the cued recall of an item decreases as the number of items bound to the same cue increases (see Watkins, 1975, for a review). Moreover, the competition is often assumed to be strength dependent, i. e., the cued recall of an item is supposed to decrease (increase) as a function of the increase (decrease) in level of its competitors' bindings to the common cue. Correspondingly, recall chances for *FRUIT-apple* should decrease if, during learning, *FRUIT-orange* is studied twice rather than once (Anderson, 1983; Mensink & Raaijmakers, 1988; Raaijmakers & Shiffrin, 1981; Rundus, 1973).

The concept of strength-dependent competition is theoretically attractive because it offers a unified account of the detrimental effects of both strengthening and cuing. Indeed, according to this concept, the strengthening of material, be it through relearning or retrieval, increases the binding level of the reprocessed items and thus makes these items stronger competitors for the not reprocessed material. Due to this change in competition conditions for renewed binding, recall of the strengthened material improves and recall of the nonstrengthened material gets worse, compared to a condition in which no strengthening takes place at all (Raaijmakers & Shiffrin, 1981; Mensink & Raaijmakers, 1988). In a similar way, strength-dependent competition also provides an explanation for why part-list cuing can cause forgetting. If the presentation of part-list cues increases the binding level of the cue items very similar to how relearning or retrieval do (Rundus, 1973; Roediger, 1973), then this enhancement should induce a competition bias and thus reduce recall of non-cue items. If true, the same mechanism would mediate the detrimental effects of relearning, retrieval, and cuing.

At least two properties of the strength dependence account are challenging. The one property is the assumption that forgetting leaves the memory representation of the forgotten material unchanged. In fact, the material is neither inhibited nor is it degraded in any way, so that no change in binding level or binding structure is supposed to occur. Rather, episodic forgetting arises only because new competing material is bound to the same cue, or competing material already bound to the common cue is strengthened in its binding level. The second property is that the account does not distinguish between changes in binding level as they occur through relearning and changes in binding level as they occur through retrieval. Indeed, this proposed equivalence between learning and retrieval is part of many computational models (Raaijmakers & Shiffrin, 1981; Mensink & Raaijmakers, 1988; Rundus, 1973). The account does also not distinguish between changes in binding level as they occur through relearning and changes as they occur through part-list cuing. Such an equivalence between learning and cuing is part of Rundus' (1973) computational framework.

A third property of strength dependence appears noteworthy. Forgetting of episodic material is assumed to arise only if other material bound to the same cue is strengthened. For instance, if *RED-blood*, *RED-cherry*, *FOOD-radish*, and *FOOD-bread* etc. are learned, then strengthening *RED-blood* should lead to impaired recall of *RED-cherry* but not to impaired recall of *FOOD-radish* or *FOOD-bread*. Indeed, increasing the level of binding between the practiced item and its cue should reduce chances for the other item which is bound to the same cue but should not impair recall of items which are bound to a different cue, e. g., *FOOD-radish*. This property of cue-dependent forgetting is part of many computational models of the past years (Raaijmakers & Shiffrin, 1981; Mensink & Raaijmakers, 1988; Rundus, 1973). Of course, the adequacy of strength dependence and the computational models which rely on it depend on the empirical soundness of all these properties. Until recently, however, these properties have not been tested directly.

1.3 Goal of the present chapter

In the past ten years, evidence has been accumulated that strength-dependent competition is not the mechanism which underlies the detrimental effects of strengthening and cuing. Rather, a more complex picture of episodic forgetting has arisen. This new picture challenges all of the three properties of the strength-dependence account outlined above, indicating that (a.) episodic forgetting does not arise from enhancing the binding level of competing material, and often, though not always, is caused by retrieval inhibition of the nonprocessed material, (b.) the proposed equivalence between learning, retrieval, and cuing is wrong and at least learning on the one hand and retrieval and cuing on the other differ, and (c.) forgetting may cross cue boundaries and be cue independent. Due to these results, a substantial modification of our picture of episodic forgetting has emerged.

The goal of this chapter is to sketch some of the landmarks of this recent development by showing how our understanding of episodic forgetting has changed in the light of new experimental evidence. This sketch is provided separately for the three forms of episodic forgetting discussed in the present chapter, i. e., relearning (section 2), retrieval (section 3), and cuing (section 4). Then, in section 5, episodic forgetting is discussed on the basis of two-stage models of recall (Mensink & Raaijmakers, 1988; Raaijmakers & Shiffrin, 1981; Rohrer, 1996), before, in the final section 6, some conclusions are offered about how forgetting affects feature binding.

2 Detrimental effects of relearning

2.1 Interference studies

The relationship between an increase in binding level as it occurs through relearning part of a studied list and episodic forgetting has been studied using quite different experimental paradigms. Many of these studies were interference studies, examining how the recall of target material varies as a function of some prior learning (proactive interference) or as a function of some subsequent learning (retroactive interference). In retroactive interference, for instance, the typical finding has been that a higher degree of interpolated learning induces greater interference than does a lower degree (Barnes & Underwood, 1959; Briggs, 1957). This finding agrees with strength-dependent competition, as higher degrees of interpolated learning should increase the binding level of the interpolated material, make these items stronger competitors, and thus cause forgetting of the previously learned target material. In fact, hardly any exceptions from this pattern have been reported.

All of the studies showing an effect of the degree of interpolated learning used the anticipation procedure during acquisition of the interpolated task (e. g., Crowder, 1976). In this procedure, subjects must learn to give the response member of a paired associate when presented with the stimulus member of the pair. On each trial the stimulus member is presented as a cue to which subjects attempt to recall or "anticipate" the associated response. Following the response, feedback is given as to the correct pairing. By cuing recall in this manner, subjects are engaged in retrieval practice with every trial of the learning task.

Using this procedure, the degree of interpolated learning is manipulated by varying the number of study trials for the interpolated task. However, as more study opportunities are given, more prescribed retrieval efforts are also being made, thus increasing the retrieval practice on the interpolated task. Because retrieval of material can cause forgetting of nonretrieved material (Anderson et al., 1994; see also section 3 below), the retrieval practice on the interpolated task may have caused the forgetting of the original task, with a higher amount of retrieval practice leading to stronger forgetting.

Bäuml (1996) examined the issue in two free-recall experiments. He let subjects study one original and then four interpolated lists. The degree of interpolated learning was manipulated by varying exposure time. In Experiment 1, where the typical confounding of retrieval practice and degree of interpolated learning was present, greater interpolated learning induced greater retroactive interference, which is consistent with prior research. However, in Experiment 2, where the degree of interpolated learning was manipulated without concomitant variation in retrieval practice, retroactive interference was the same, whether the interpolated lists had been learned well or poorly. Therefore, greater interpolated learning did not increase the amount of retroactive interference, a finding which challenges the strength dependence account (see DaPolito, 1966, for a related result in proactive interference.)

2.2 The list-strength effect

A more recent illustration of the apparent relationship between an enhancement in binding level as it occurs through relearning and episodic forgetting comes from a series of studies on what has been termed the list-strength effect by Ratcliff et al. (1990). Using a so-called mixed-pure paradigm, Ratcliff et al. presented subjects three kinds of item lists: pure-strong lists containing strong items only, pure-weak lists containing weak items only, and mixed lists containing half weak and half strong items. Strengthening was accomplished either by increasing the exposure time or the number of repetitions of the to-be-strengthened items. In free-recall tests Ratcliff et al. found that (a) relatively more strong items were recalled from the mixed lists than from the pure-strong lists, and (b) relatively more weak items were recalled from the pure-weak lists than from the mixed lists, a pattern consistent with strength-dependent competition.

The results of Ratcliff et al. (1990), however, might also have been induced by uncontrolled retrieval practice. Indeed, if the strong items from a mixed list are retrieved earlier than the weak items (Anderson et al., 1994; Wixted, Ghadisha, & Vera, 1997), then recall performance of strong items from mixed lists should be higher than from pure-strong lists; in fact, in the pure-strong lists the retrieval of items in the first testing positions should lead to recall impairment of the still-to-be-remembered items, yielding lower performance, on average, than in the mixed lists. Similarly, recall performance of weak items from mixed lists should be lower than from pure-weak lists, because, on average, there is less retrieval-induced recall impairment for the weak items in the pure-weak lists than in the mixed lists. Thus, the list-strength effect as found by Ratcliff et al. need not necessarily have been the result of strength-dependent competition but might also have been caused by output-order biases and a process of retrieval-induced forgetting.

Bäuml (1997) reported an experiment in which categorizable lists were employed and some categories in each list contained strong items only, some weak items only, and some both strong and weak items. Strengthening was accomplished by varying the exposure time of the items. The testing sequence of the items from each category was controlled by the use of category-plus-first-letter cues. When the typical confounding of strengthening and output order was mimicked, list-strength effects were found, which is consistent with prior research. However, when this confounding was eliminated, the list-strength effects disappeared: Neither the recall of strong nor the recall of weak items varied with the strength of the other category exemplars (see Figure 2). These results indicate that enhancing the binding level of a subset of previously learned material per se does not impair recall of the unprocessed material, an indication which is in line with the results from other work (Anderson, Bjork, & Bjork, 2000a; Ciranni & Shimamura, 1999).

** Figure 2 about here **

2.3 Summary

The results from a number of recent studies have demonstrated that enhancing the binding level of a subset of previously learned material through additional learning may cause forgetting of the not reprocessed material, or not. Whether it causes forgetting depends on the recall task and on whether output order at test is controlled. If output order is not controlled and subjects recall the reprocessed material first and the not reprocessed material last - which is the preferred output order in free recall (Wixted et al., 1997) - then the typical relationship between additional learning and impairment arises. If, however, output order is controlled and subjects recall the not reprocessed material first, then reprocessing does not cause impairment. These results challenge strength-dependent competition as a general explanation of the detrimental effects accompanied by increases in items' binding level. Rather, they suggest that such effects arise from a noncontrol of retrieval factors at test. The importance of retrieval for episodic forgetting is stressed in the next section.

3 Detrimental effects of retrieval

3.1 Recall-specific forgetting

The relationship between an increase in binding level as it occurs through the retrieval of part of a studied list and episodic forgetting has mostly been studied using the retrieval-practice paradigm (Anderson et al., 1994; Anderson & Spellman, 1995; see Levy & Anderson, 2002, for a review). In this paradigm, subjects are presented a categorized list with several items from each category (e. g., *FRUIT-apple*, *FRUIT-orange*), and, subsequently, retrieve half of the items from each category given partial word stems of these items as retrieval cues (e. g., *FRUIT-ap___*).

Strengthening the retrieved items in this way typically impairs later recall of the non-retrieved items (e. g., *FRUIT-orange*), relative to a control condition in which there is no such retrieval practice. This pattern is consistent with strength-dependent competition, because the retrieval practice increased the binding level of the practiced items (e. g., *FRUIT-apple*) and thus made these items stronger competitors for the unpracticed material (e. g., *FRUIT-orange*; Mensink & Raaijmakers, 1988; Raaijmakers & Shiffrin, 1981).

There is evidence, however, that retrieval-induced forgetting is not caused by an increase in binding level of the practiced material. This evidence comes partly from the studies cited above (see section 2). In these studies, it was demonstrated that an increase in binding level per se does not cause forgetting and that possible detrimental effects of relearning arise only as a result of output order biases at test. However, detrimental effects of retrieval have been reported both when output order at test was not controlled and when it was controlled (Anderson et al., 1994; Anderson & Spellman, 1995). Therefore, retrieval-induced forgetting should not be due to changes in binding level of the retrieved material.

A study by Anderson et al. (2000a) addressed the issue more directly. They let subjects learn a categorized list (e. g., *FRUIT-apple*, *FRUIT-orange*). Then, subjects either retrieved a subset of a category's items given the word stem of the items as a retrieval cue (*FRUIT-ap___*; competitive condition), or were provided the same items intact and were asked to recall the appropriate category name by using the exemplar and a stem as cues (*FR___-apple*, noncompetitive condition). Although the two conditions led to comparable strengthening of the practiced items (*apple*), only the competitive condition but not the noncompetitive one induced forgetting of the nonstrengthened material (*orange*) in a final recall test. This finding indicates that retrieval-induced forgetting is not caused by the strengthening of competitors per se but rather is due to a recall-specific process (see Ciranni & Shimamura, 1999, for a related result).

Bäuml (2002) provided further evidence for recall-specific processes in retrieval-induced forgetting by investigating a situation in which the retrieved and non-retrieved items are not part of the same experiential episode and task. Subjects learned a categorized list (e. g., *FRUIT-apple*, *FRUIT-orange*) which they had to recall later in the experiment. In a separate intermediate phase they repeatedly generated related items from semantic memory (e. g., *FRUIT-ana___*, *FRUIT-ki___*), or were presented the same items intact for study (e. g., *FRUIT-ananas*, *FRUIT-kiwi*). Only the semantic generation of items but not their presentation for study induced forgetting of the initially learned items (see Figure 3). This result indicates that semantic generation can cause recall-specific episodic forgetting, thus generalizing the findings by Ciranni and Shimamura (1999) and Anderson et al. (2000a) from episodic practice to semantic practice.

** Figure 3 about here **

3.2 Retrieval-induced forgetting as retrieval inhibition

There is a surprising role of item strength in retrieval-induced forgetting. Results by Anderson et al. (1994) indicate that items which are strongly bound to a common cue are subject to retrieval-induced forgetting, whereas items which are weakly bound to the common cue do not show forgetting. Indeed, if subjects are presented categorized material with the categories consisting either of high-frequency (*FRUIT-apple*) or low-frequency (*FRUIT-olive*) category members, then retrieval practice on a subset of the items has been found to impair later recall of a category's strong items (e. g., *FRUIT-apple*) but not a category's weak items (e. g., *FRUIT-olive*;

see Bäuml, 1998, for related results). This pattern appears to be independent of whether the practiced items are strongly or weakly bound to the common cue.

This difference between strongly and weakly bound items was interpreted as evidence for the action of a retrieval inhibition mechanism. This view rests on the assumption that during retrieval of the to-be-practiced items not-to-be-practiced items which are bound to the same cue interfere and, to guarantee a successful recovery of the to-be-practiced items, need to be inhibited. Because items strongly bound to the common cue are supposed to induce more interference than items weakly bound to that cue, they should be subject to more inhibition than the weakly bound items. This role of item strength is interesting as it additionally challenges strength dependence as a possible explanation of retrieval-induced forgetting. According to strength dependence, weakly bound items should suffer proportionally more forgetting than strongly bound items (see Anderson et al., 1994, Appendix A), which is not the case.

As another challenge to strength dependence, Anderson and Spellman (1995) provided evidence that retrieval-induced forgetting is cue independent. They let subjects study lists consisting of items like *GREEN-emerald*, *GREEN-lettuce*, *SOUP-mushroom*, and *SOUP-minestrone*. The participants then repeatedly retrieved *GREEN-emerald* and thus caused forgetting of *GREEN-lettuce* on a later recall test. More important, the repeated retrieval of *GREEN-emerald* caused forgetting of *SOUP-mushroom* as well, though not of *SOUP-minestrone*. According to Anderson and Spellman, this finding suggests that, because *lettuce* and *mushroom* are vegetables and thus share a number of semantic features, the inhibition of *lettuce* spread to the representation of *mushroom* and thus impaired recall of *SOUP-mushroom*. The fact that forgetting for *mushroom* arose although the cue at test (*SOUP*) was different to the cue used in the retrieval-practice phase (*GREEN*) indicates that retrieval-induced forgetting suppresses an item's memory representation itself and, therefore, is cue independent (see Ciranni & Shimamura, 1999, for a related result).

3.3 Retrieval-induced forgetting and integration

Retrieval-induced forgetting can be greatly reduced or even eliminated if participants enhance the binding between competing memories, a process called integration. Anderson and McCulloch (1999), for instance, found that encouraging participants to interrelate the exemplars of studied categories during the study phase largely reduced retrieval-induced forgetting. In studies of the fan effect, Radvansky (1999) found a similar pattern of less forgetting when participants integrated propositional knowledge into what he called location schemata. Analogously, retrieval-induced forgetting was found to be reduced or eliminated if there is a high degree of semantic similarity between practiced and unpracticed items (Anderson, Green, & McCulloch, 2000b; Bäuml & Hartinger, 2002). By enhancing the binding between items through integrating facts into more cohesive representations, participants appear to experience less interference between related facts, require less inhibition, and thus are protected from impairment (Anderson & Bell, 2001; Smith, Adams, & Schorr, 1978). Anderson and Spellman's (1995) feature inhibition theory provides a rationale for these results (see Anderson et al., 2000b, for details).

All of these findings are consistent with recent work employing Deese-Roediger-McDermott (DRM) lists (Deese, 1959; Roediger & McDermott, 1995). DRM lists consist of items which are all strongly bound to a so-called critical item. When presented to participants, such lists can create high levels of false recall of the unstudied critical item. For instance, if participants study words like *pillow, bed, silence*, and so forth, all of which are the strongest semantic associates to the unpresented critical item, *sleep*, then they are highly likely to recall the critical item falsely. DRM lists differ substantially in the degree to which they cause false memories (Stadler, Roediger, & McDermott, 1999). Because this variation in false recall level is largely due to differences in the binding between the lists' critical item and the noncritical ones (Roediger, Watson, McDermott, & Gallo, 2001), high false recall lists should show more integration than low false recall lists and thus show less retrieval-induced forgetting.

Bäuml and Kuhbandner (2003) confirmed this prediction. They ran two experiments in which they examined the effect of retrieval practice on a subset of the items from DRM lists on recall of the lists' "critical" items. In Experiment 1, the critical items were part of the studied lists, thus addressing these items' veridical recall; in Experiment 2 they were not studied, thus addressing these items' false recall. As predicted, retrieval practice induced an integration effect in veridical recall, with substantial forgetting of critical items in lists with low false recall levels and no forgetting in lists with high false recall levels. However, retrieval practice reduced not only critical items' veridical recall but also their false recall. This latter result is consistent with the hypothesis that false recall reflects activation during study (Kimball & Bjork, 2002; Reysen & Nairne, 2002) and that retrieval of related items can lead to inhibition of the activated, unstudied critical items very similar to how retrieval inhibits studied material.

3.5 Summary

Results from recent research show that increasing the binding level of a subset of previously learned material through retrieval practice can lead to forgetting of the not reprocessed material. This forgetting, however, is not caused by the reprocessing per se but rather by recall-specific inhibition, whereby interfering, not-to-be-retrieved material is inhibited to guarantee successful recovery of to-be-retrieved material. Retrieval inhibition is particularly strong if the interference potential of the not-to-be-practiced material is high and if the similarity between practiced and unpracticed items is only moderate. It applies to both veridical and false memories. Retrieval inhibition affects the unpracticed items by reducing the binding between the items and their cue(s) and/or reducing the intraitem binding, as is suggested by the cue independence finding.

4 Detrimental effects of cuing

4.1 Retrieval competition

The detrimental effects of cuing have been shown in a number of different paradigms. Often subjects are presented a categorized list and, at test, receive the category name and a subset of a category's items as a retrieval cue for recall of the remaining items. Typically, such cuing impairs recall of the remaining items, compared to a control condition in which only the category name is provided as a retrieval cue (Slamecka, 1968; Roediger, 1973). The detrimental effect of part-list cuing has been found to be fairly robust, occurring with both categorized and uncategorized lists, and with either intralist or extralist items as cues (see Roediger & Neely, 1982, or Nickerson, 1984, for reviews).

A still very popular account of part-list cuing is retrieval competition (Rundus, 1973; see also Kimball & Bjork, 2002). This account, which is consistent with strength-dependent competition, assumes that part-list cuing strengthens the binding level of the cue items and thus leads participants to covertly retrieve (the more strongly bound) cue items before (the more weakly bound) noncue items at test. In this way, a competition bias for renewed binding is introduced, favoring covert retrieval of cue items at the expense of retrieval of noncue items. Because each retrieval of a cue item reflects a failure to retrieve a new noncue item and the retrieval process is assumed to stop after a critical number of failures, this bias can lower recall chances for the noncue items, and thus cause the detrimental effect of part-list cuing.

If part-list cuing is really mediated through strengthening-induced output order biases at test, then the forgetting should disappear if the bias is eliminated. Exactly such a pattern has been found in the list-strength effect, which is caused by increasing the binding level of part of a list through relearning (Bäuml, 1997; see section 2 above). In a very recent study, Bäuml and Aslan (2004) directly compared the effects of cuing and relearning when controlling for output order biases. Subjects learned category exemplars consisting of target and nontarget items. In a subsequent phase, the nontarget items were reexposed, either for relearning or for use as a retrieval cue at test. This reexposure occurred immediately before test, mimicking typical part-list cuing, or separated from test by a distractor task, mimicking typical part-list relearning. At test, the category-plus-first-letter cues of the target items were presented and subjects were instructed to recall the target items, thus controlling for output order.

The results replicated prior work by showing that part-list relearning has no detrimental effect on target material if output order is controlled. By contrast, however, a detrimental effect of part-list cuing was found. This held true both when the reexposure occurred immediately before test and when reexposure was separated from test by a distractor task (see Figure 4). This finding disagrees with the proposal that part-list cuing is due to a competition bias caused by increases in the binding level of the cue items.

** Figure 4 about here **

4.2 Strategy disruption and retrieval inhibition

Two other prominent accounts of part-list cuing have been suggested in the past years. The one account is strategy disruption. According to this hypothesis (Basden & Basden, 1995; Basden, Basden, & Galloway, 1977), the presentation of cue items disrupts retrieval by forcing a serial recall order that is inconsistent with subjects' interitem bindings in a list. Following this line of reasoning, part-list cuing induces a change in the retrieval process from a more effective one when cues are absent to a less effective one when they are present (see Sloman, Bower, & Rohrer, 1991, and Raaijmakers & Shiffrin, 1981, for related suggestions). Part-list cuing, therefore, should be mediated by quite a different mechanism than retrieval-induced forgetting.

The other account of part-list cuing is retrieval inhibition (Anderson et al., 1994). Like retrieval competition, this account assumes that the presentation of cue items leads to an increase in these items' binding level and that this increase induces early covert retrieval of the cue items at test. In contrast to Rundus' account, however, this covert retrieval is not supposed to cause forgetting because of biased retrieval competition but rather because of retrieval inhibition. Other work has shown that overt retrieval of a subset of previously learned material can cause retrieval inhibition of the nonretrieved material (see section 3 above). If covert retrieval of items has a similar effect on nonretrieved items as the items' overt retrieval, then the covert retrieval of cue items should cause retrieval inhibition of noncue items as well. As a result, part-list cuing and retrieval-induced forgetting should show a number of parallels.

Indeed, the results from several recent studies suggest that the detrimental effects of retrieval practice and part-list cuing have many things in common. Bäuml, Kissler, and Rak (2002), for instance, showed that the same effect of item strength which is present in retrieval-induced forgetting holds in part-list cuing as well. They found detrimental effects of part-list cuing for items strongly bound to the common cue but not for items weakly bound to the cue. Hicks and Starns (2004) demonstrated that retrieval-induced forgetting occurs not only in recall but also in recognition, a result which mimics a similar finding in part-list cuing (Todres & Watkins, 1981). Furthermore, it was shown that not only the presentation of semantically related extralist items as retrieval cues (Roediger, Stellon, & Tulving, 1977; Watkins, 1975) but also the generation of such extralist items (Bäuml, 2002) can cause forgetting of previously learned material.

Bäuml and Kuhbandner (2003) provided a direct comparison of the effects of retrieval practice and part-list cuing in DRM lists. They compared the effects of retrieval practice on a subset of the items and of the presentation of those items as retrieval cues at test on veridical and false recall of the lists' "critical" items. Just like retrieval practice (see section 3 above), cuing induced an integration effect in veridical recall, with substantial forgetting in DRM lists with low false recall levels and no forgetting in DRM lists with high false recall levels. Just like retrieval practice, cuing reduced not only critical items' veridical recall but also their false recall (see Figure 5). These parallels held both in pattern and in size. They are consistent with the view that the same mechanism which mediates retrieval-induced forgetting underlies part-list cuing as well. The results thus challenge the strategy disruption account and favor a retrieval-inhibition account of part-list cuing.

** Figure 5 about here **

4.3 Instructed retrieval inhibition

The original retrieval-inhibition account of part-list cuing (Anderson et al., 1994) assumes that, just like retrieval competition, the presentation of cue items leads to an increase in these items' binding level, this increase induces early covert retrieval of the cue items at test, and this covert retrieval of the cue items causes retrieval inhibition of the noncue items. In this sense, the retrieval-inhibition account depends on the validity of the proposal that part-list cuing is due to the increase in binding level of the cue items, a proposal which is challenged by the Bäuml and Aslan (2004) finding.

Although the Bäuml and Aslan finding rules out all types of strengthening accounts of part-list cuing, it is consistent with the view that covert retrieval of cue items is at the heart of the part-list cuing effect (Anderson et al., 1994; Roediger, 1973; Rundus, 1973). Unlike previous accounts, however, the finding suggests that this covert retrieval is not caused by enhancing the binding level of cue items but rather reflects an instructional effect. In fact, by directly comparing the effects of part-list relearning – i. e., the reexposure of items for additional learning – and part-list cuing – i. e., the reexposure of the same items for use as a retrieval cue at test –, Bäuml and Aslan could demonstrate that the detrimental effect of part-list cuing is caused by instruction. The instruction to use items as cues apparently induces covert retrieval of the cue items and thus leads to retrieval inhibition of noncue items.

4.4 Patients data

Two recent studies examined the detrimental effect of part-list cuing in amnesic and schizophrenic patients. Using categorized lists, Bäuml et al. (2002) demonstrated that, while in healthy people the detrimental effect of part-list cuing is restricted to items strongly bound to the category cue, in amnesia patients the forgetting extends to items which are weakly bound to the cue. This finding was independent of the presence of executive dysfunctions in some of the patients. On the basis of the retrieval-inhibition account of part-list cuing, these results indicate that amnesic patients show more retrieval inhibition than healthy controls. They also suggest that primarily medial temporal lobe structures mediate the detrimental effect of part-list cuing.

In a more recent study, Kissler and Bäuml (in press) used the same experimental setup to examine part-list cuing in schizophrenic patients. Like the amnesic people, the schizophrenic people showed substantial recall deficits. Unlike the amnesic patients, however, the schizophrenic patients did not exhibit increased susceptibility to part-list cuing effects, indicating that schizophrenic patients do not show enhanced retrieval inhibition. Moreover, because schizophrenic people have repeatedly been shown to exhibit deficits in executive control and response suppression related to prefrontal cortex functioning (Braver, Barch, & Cohen, 1999; Perlstein, Dixit, Carter, Noll, & Cohen, 2003), this result suggests that it is not the frontal lobe structures which mediate the detrimental effect of part-list cuing. This suggestion agrees with the finding that amnesic patients with executive dysfunctions show the same detrimental effect as amnesic patients without executive dysfunctions (Bäuml et al., 2002).

Together, the results for the amnesic and schizophrenic patients indicate that a certain type of feature binding process in temporal lobe structures and not strategic control mechanisms mediated by the frontal lobes are responsible for the detrimental effect of part-list cuing. This pattern of results provides another parallel between the detrimental effects of part-list cuing and retrieval practice. Indeed, examining inhibitory control mechanisms in patients with lesions to the frontal lobes and patients with lesions to the temporal lobes, Conway and Fthenaki (2003) recently found that retrieval-induced forgetting was affected in patients with temporal lobe lesions whereas patients with frontal lobe lesions showed normal retrieval-induced forgetting. These findings are consistent with the proposal that part-list cuing and retrieval-induced forgetting are mediated by similar mechanisms.

4.5 Summary

The results from recent research indicate that the detrimental effect of part-list cuing is not caused through biases in items' competition for renewed binding, or strategy disruption. Instead, the results agree with the view that part-list cuing is caused by retrieval inhibition. It is suggested that the cuing instruction leads to covert retrieval of the cue items at test and this covert retrieval then causes retrieval inhibition of the noncue items. The inhibition supposedly reduces the items' binding level and thus reduces the items' recall chances. As a corollary, this proposal claims that retrieval-induced forgetting and part-list cuing are mediated by similar mechanisms. Consistent with this view, a number of quantitative and qualitative parallels between the two forms of forgetting have emerged in recent work.

5 Forgetting mechanisms

5.1 Inhibitory mechanisms

Models of recall are often two-stage models, where in the first stage an item's relative strength and in the second stage an item's absolute strength is of importance for recall (Gronlund & Shiffrin, 1986; Raaijmakers & Shiffrin, 1981; Rohrer, 1996; Wixted et al., 1997). Indeed, in the first stage, an item is sampled from a set of items according to a relative-strength rule, which determines the item's response latency: A high relative strength leads to a fast response and a low one to a slow response. In the second stage, a sampled item is recovered into consciousness if its absolute strength exceeds some threshold. Thus, whereas an item will eventually be sampled, it may not be recovered because its memory representation is too weak to exceed threshold.

On the basis of such two-stage models of recall, the question arises of whether retrieval inhibition prevents an item from being sampled at all, or whether it permits sampling but prevents recovery. This would occur if inhibition reduced the absolute strength of the inhibited item, so that it no longer exceeds the recovery threshold. If a reduction in binding level was equivalent to a reduction in the item's absolute strength, then retrieval inhibition should reflect a recovery problem and not prevent the item from being sampled.

As Rohrer, Wixted, and colleagues (Rohrer, 1996; Rohrer, Wixted, Salmon, & Butters, 1995; Wixted & Rohrer, 1994) demonstrated, response latency analysis can be used to examine whether a change in recall performance is due to a change in sampling or a change in recovery. Indeed, if items are reduced in their absolute strength while their relative strength is maintained – which may occur if retrieval inhibition reduced the binding level of the unpracticed items – then recall frequency of the unpracticed items should decrease while their response latency should not be influenced.

Bäuml, Zellner, and Vilimek (2003) reported an experiment in which they measured recall frequencies and response latencies of retrieval-practiced and not retrieval-practiced items. They let participants study categorized lists with each category (e. g., *ANIMALS*) consisting of exemplars from two different semantic subcategories (e. g., *PREDATORS, HOOFED ANIMALS*). In the retrieval-practice phase, subjects repeatedly retrieved the items from one of the two subcategories of a category (e. g., *PREDATORS*), before, in the final test, they separately recalled the items from both subcategories (e. g., *HOOFED ANIMALS*, *PREDATORS*). As expected, retrieval practice improved later recall of the practiced items (e. g., *PREDATORS*) but impaired recall of the unpracticed items (e. g., *HOOFED ANIMALS*). Most interestingly, both types of items showed no change in their response latencies, compared to a control condition in which no items were practiced at all. This result, which was replicated in a second experiment, is consistent with the view that retrieval inhibition reduces the items' binding level and thus reduces the items' absolute strength. As a result, the inhibited items may eventually be sampled but they do no longer exceed the recovery threshold (see Zellner & Bäuml, 2004, for related results).

5.2 Retrieval competition

The results from the retrieval-induced forgetting experiments contrast sharply with those from interference studies. Like in retrieval-induced forgetting, interference leads to reduced recall frequencies. Unlike retrieval-induced forgetting, however, interference leads to a strong increase in response latencies. Wixted and Rohrer (1994) demonstrated such a pattern in a proactive-interference paradigm and Rohrer (1996) showed the same point when varying amount of to-be-learned material within lists. This increase in response latency suggests that interference already acts at the sampling stage: The binding of new material reduces the relative strength of target material and thus lowers the material's chances for being sampled. These findings are consistent with the view that interference and retrieval-induced forgetting are caused by quite different mechanisms. Interference reflects enhanced competition for renewed binding, which reduces the relative strength of items and thus lowers their chances for being sampled. Retrieval-induced forgetting is due to retrieval inhibition, which reduces the binding level of items and thus lowers their absolute strength and chances for being recovered.

5.3 Summary

The results from very recent work suggest that retrieval inhibition does not prevent inhibited items from being sampled. Rather, by reducing the items' binding level, inhibition reduces the absolute strength of inhibited items so that they can no longer be recovered. Retrieval inhibition thus is quite different from retrieval competition, where the binding of additional material induces forgetting by increasing the competition between items for renewed binding. This increased competition leads to a reduction in the items' relative strength and lowers sampling chances. Thus, retrieval competition reflects a failure at the sampling stage of recall, whereas retrieval inhibition reflects a failure at the recovery stage.

6 Conclusions

Experimental results from the past decade clearly demonstrate that the detrimental effects of (re-)learning, retrieval, and cuing are not due to strength-dependent competition. According to strength dependence, forgetting of an episode arises because new material is bound to the common cue, or material already bound to the common cue is strengthened in its binding level. Because (re-)learning, retrieval, and cuing lead to an increase in items' binding level, it has been argued that it is this increase which is at the heart of the detrimental effects of the three forms of episodic reprocessing (Raaijmakers & Shiffrin, 1981; Mensink & Raaijmakers, 1988; Rundus, 1973). For none of the three forms of forgetting, however, this prediction could be confirmed.

Recent results from interference studies suggest a modification of strength-dependent competition to non-strength-dependent competition. Indeed, strong competitors have been found to induce the same amount of forgetting of target material as weak competitors. This has been demonstrated both when using classical interference paradigms (Bäuml, 1996, DaPolito, 1966) and when using within-list strength manipulations (Anderson et al., 2000a; Bäuml, 1997; Ciranni & Shimamura, 1999). These results suggest that interference effects are caused by the binding of new material to a common cue but not by increasing the binding level of already bound competitors. The change in the binding structure enhances competition and thus reduces the relative strength of single items (Wixted & Rohrer, 1994). This change affects the sampling of the items, and thus causes forgetting.

Results from retrieval-induced forgetting studies point to retrieval inhibition rather than any variants of (strength-dependent) competition as the major source of the recall impairment. According to inhibition, retrieval suppresses interfering, not-to-be-retrieved material to guarantee the recovery of to-be-retrieved material (Anderson et al., 1994; Anderson & Spellman, 1995). As opposed to interference effects, retrieval-induced forgetting reflects a change in the binding level of forgotten items. This change does not exclude inhibited items from the sampling process but rather leads to failures in the items' recovery process (Bäuml et al., 2003).

Recent work on part-list cuing indicates that not only the detrimental effects of retrieval but also the detrimental effects of cuing are caused by retrieval inhibition. As opposed to retrieval-induced forgetting which is caused by overt retrieval, however, part-list cuing seems to be caused by covert retrieval. Indeed, experimental results indicate that the instruction to use items as cues induces covert retrieval of the cue items at test and thus leads to retrieval inhibition of noncue items (Bäuml & Aslan, 2004). Consistent with this view, a number of quantitative and qualitative parallels between the detrimental effects of retrieval and cuing have been reported in recent research (Bäuml & Kuhbandner, 2003; Hicks & Starns, 2004; Zellner & Bäuml, in press).

This chapter focused on unintentional episodic forgetting. In fact, in neither interference nor retrieval-induced forgetting or part-list cuing it is typically the goal of subjects to impair later recall of the nonprocessed material. In this sense, these forms of forgetting differ from other forms of forgetting in which subjects wish to intentionally forget material. Such intentional forgetting, as it occurs for instance in the directed-forgetting paradigm (Bjork, 1970, 1989), has also been explained in terms of retrieval inhibition (see MacLeod, 1998, for a review). There is recent evidence, however, that retrieval inhibition in intentional forgetting is not the same as retrieval inhibition in unintentional forgetting (Kimball & Bjork, 2002; Perfect, Moulin, Conway, & Perry, 2002). Discovering exactly how the two types of inhibition are related and how they differ in their effects on feature binding is an important task for future research.

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FIGURE CAPTIONS

Figure 1: Three forms of reprocessing episodic material. *Relearning*: a subset of the previously studied material is reexposed for additional learning. *Retrieval practice*: the word stems of a subset of the previously studied material are presented and subjects are asked to retrieve the items that correspond to the cues. *Part-list cuing*: a subset of the previously studied material is reexposed for use as a retrieval cue at test. Note that the presentation of the cue items may also occur as part of the testing procedure; in this case, only the noncue items are to be recalled (see Bäuml & Aslan, 2004, for details).

Figure 2: Recall percentages and standard errors on a category-plus-first-letter cued-recall test as a function of item type and category composition. Pure categories are categories, in which all items are strong items or all items are weak items; mixed categories are categories in which half of the items are strong items, half are weak items (from Bäuml, 1997).

Figure 3: Recall percentages and standard errors on a category-plus-first-letter cued-recall test as a function of item type and experimental condition. Ge- = items of which related material was *generated from semantic memory*; Nge = items of which *no* related material was *generated from semantic memory*. Pr- = items of which related material was *presented for study*; Npr = items of which *no* related material was *presented for study* (from Bäuml, 2002).

Figure 4: Mean target item recall and standard errors on a category-plus-first-letter

cued-recall test as a function of type of reprocessing and delay between reprocessing and test. The dashed lines indicate performance in the control condition in which no reprocessing took place (from Bäuml & Aslan, 2004).

Figure 5: Recall percentages and standard errors for critical items' veridical and false recall as a function of recall condition (retrieval practice/part-list cuing/control condition). Veridical recall refers to the case in which both the noncritical and the critical items were part of the studied DRM lists; false recall refers to the case in which only the noncritical but not the critical items were part of the studied lists. The results shown are based on 16 DRM lists, including lists with relatively high false recall levels and lists wit relatively low false recall levels (from Bäuml & Kuhbandner, 2003).

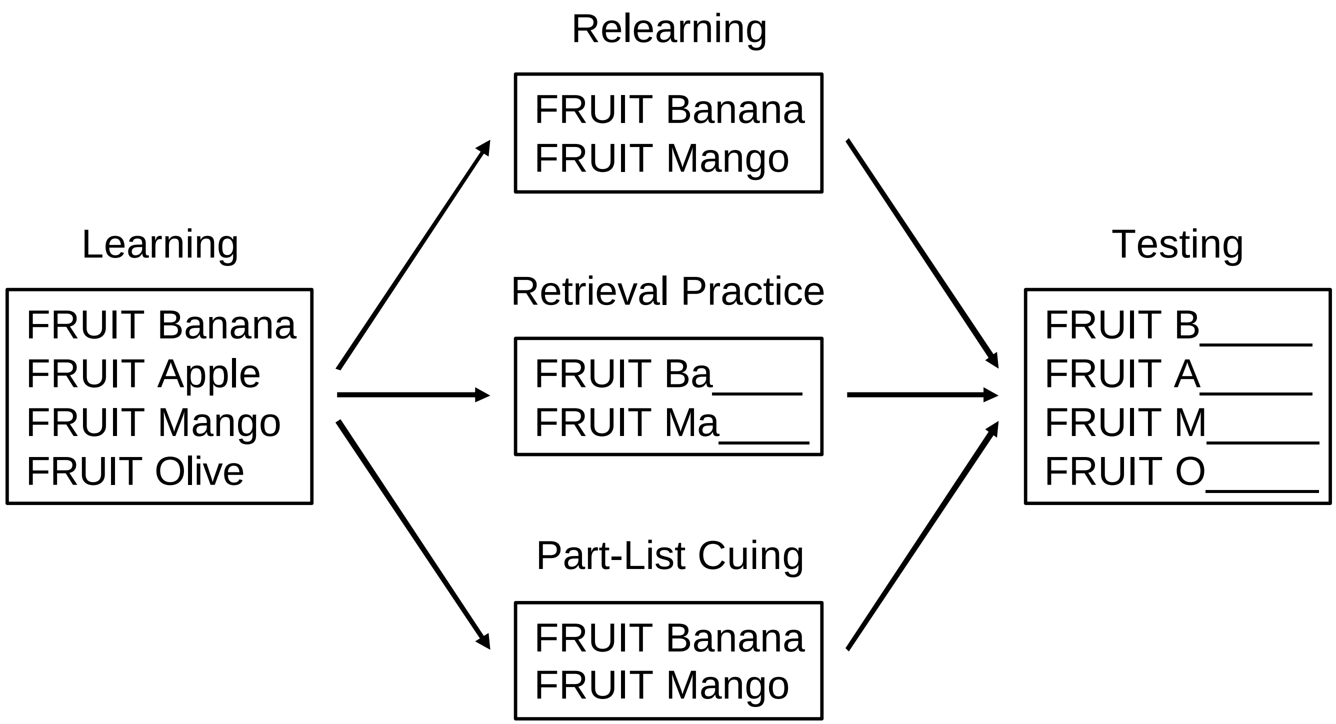
Relearning
FRUIT Banana
FRUIT Mango
Learning
FRUIT Banana
FRUIT Apple
FRUIT Mango
FRUIT Olive
Retrieval Practice
FRUIT Ba____
FRUIT Ma____
Testing
FRUIT B_____
FRUIT A_____
FRUIT M_____
FRUIT O_____
Part-List Cuing
FRUIT Banana
FRUIT Mango

Figure 1:

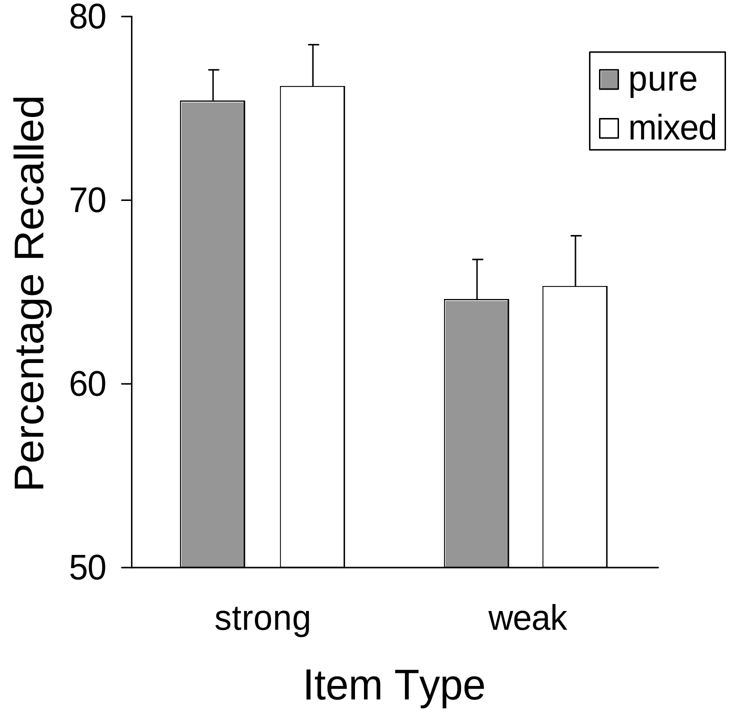
80
70
60
50
Percentage Recalled
pure
mixed
strong
weak
Item Type

Figure 2:

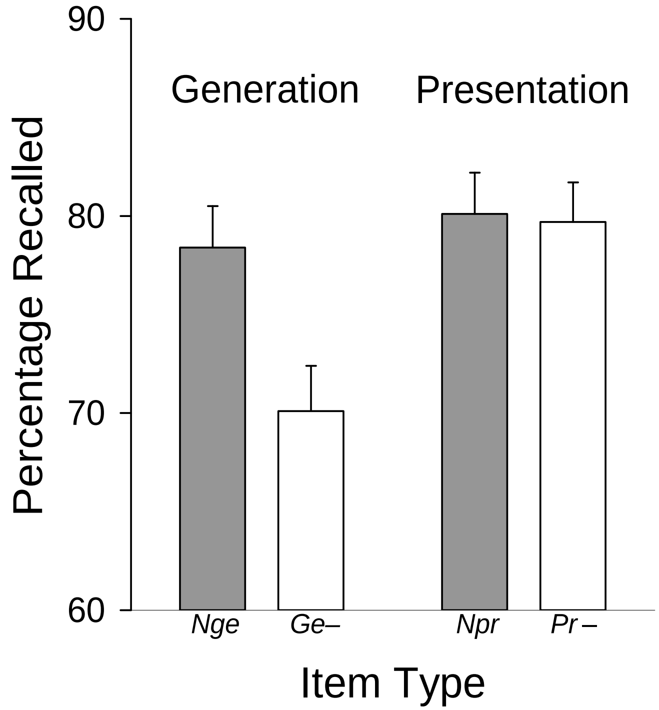
90
80
70
60
Percentage Recalled
Generation
Presentation
Nge
Ge–
Npr
Pr –
Item Type

Figure 3:

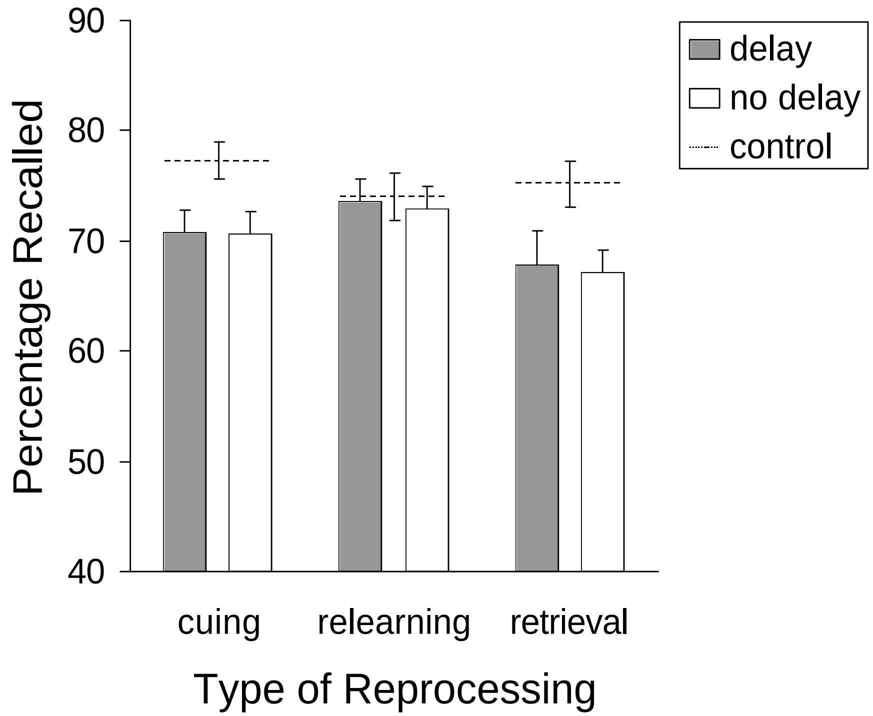
90
80
70
60
50
40
Percentage Recalled
delay
no delay
control
cuing
relearning
retrieval
Type of Reprocessing

Figure 4:

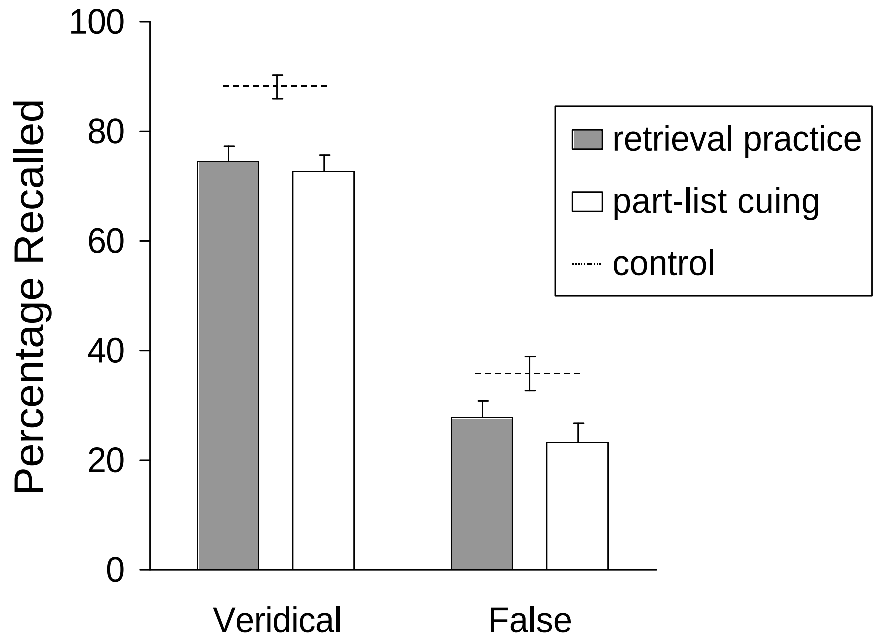
Percentage Recalled
100
80
60
40
20
0
Veridical
False
retrieval practice
part-list cuing
control

Figure 5: