

Making Memories Unavailable

The Inhibitory Power of Retrieval

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Abstract. Research from the past decades has shown that cuing and retrieval are not always beneficial for episodic memory and can also be detrimental. Prior work assumed that these detrimental effects are caused by retrieval blocking, in which cuing and retrieval strengthen material and the repeated involuntary sampling of the strengthened material hinders subsequent recall of nonstrengthened targets. Using a new experimental paradigm and an extended range of memory tests, recent research indicates that the detrimental effects of retrieval and cuing occur across a wide range of memory tests and are likely to be the result of inhibitory processes. These inhibitory processes impair the nonretrieved and noncue items' memory representation and make these items unavailable in memory. The recent results and the new theory are reviewed and discussed.

Keywords: memory retrieval, retrieval-induced forgetting, part-list cuing, retrieval inhibition, retrieval blocking

Human episodic memory depends greatly on the presence of adequate retrieval cues. This has been demonstrated in numerous experimental studies (e.g., Tulving, 1974), in computational modeling work (e.g., Raaijmakers & Shiffrin, 1981), and also in applied settings (Geiselman, Fisher, MacKinnon, & Holland, 1985). On the other hand, there is evidence that cuing is not always beneficial and can even be detrimental. Such evidence comes from studies on part-list cuing. In part-list cuing, it is studied how the presence of a subset of previously learned material (i.e., *farmer, dentist* from the studied list *farmer, baker, clerk, dentist*) affects recall of the remaining (noncue) items (i.e., *baker, clerk*). Ironically, over a wide range of experimental contexts, part-list cuing has been found to impair recall of the remainder rather than to improve it (Slamecka, 1968; for a review, see Nickerson, 1984).

The retrieval process itself also shows a pattern of beneficial and detrimental effects. Evidence for beneficial effects of retrieval arises from studies on the testing effect, in which retrieval of episodes has been shown to enhance later recall of these episodes (Hogan & Kintsch, 1971; Roediger & Karpicke, 2006). Evidence for detrimental effects of retrieval arises from the classic studies on output interference. In output interference, it is investigated how cued recall performance varies as a function of targets' testing position. Results from many experiments have shown that recall decreases as the testing position increases (Smith, 1971), which indicates that the retrieval process itself can impair memory performance (for a review, see Roediger & Neely, 1982).

For a long time, the standard explanation of the detrimental effects of cuing and retrieval was retrieval blocking (Raaijmakers & Shiffrin, 1981; Roediger, 1973; Rundus, 1973). At the heart of retrieval blocking is the assumption

that both reexposure and retrieval of material strengthen the material's memory representation and then block access to the nonstrengthened (weaker) material by involuntarily sampling the strengthened (stronger) material again and again. In output interference, such strengthening was suggested to be caused by item recall in the first testing positions, which blocks recall of the still-to-be-remembered items on later testing positions. In part-list cuing, the strengthening was suggested to occur through reexposure of the cue items, which blocks recall of the noncue items (Roediger, 1973; Rundus, 1973; Figure 1a, 1b).

Blocking is due to a strengthening-induced bias in retrieval competition. It has no direct effect on the forgotten material's retrieval routes or its memory representation. Effects of blocking, therefore, should be restricted to recall tasks with a high degree of retrieval competition, i.e., free recall tasks and cued recall tasks in which several items share a common cue. In contrast, effects of blocking should be absent in memory tests in which retrieval competition is expected to be largely reduced, i.e., recognition tests and tests in which item-specific probes are provided as retrieval cues.

Using a new experimental paradigm and an extended range of memory tests, results from recent studies indicate that the detrimental effects of retrieval and cuing generalize to a wide range of memory tests, including recognition and tests employing item-specific probes. These results suggest that the two types of forgetting are not mediated by retrieval blocking but rather are the result of inhibitory processes, affecting either the retrieval routes between the items and their cues or the memory representation of the items itself (Figure 1c, 1d). The major results from these recent studies and current theory on the two detrimental effects are reviewed next.

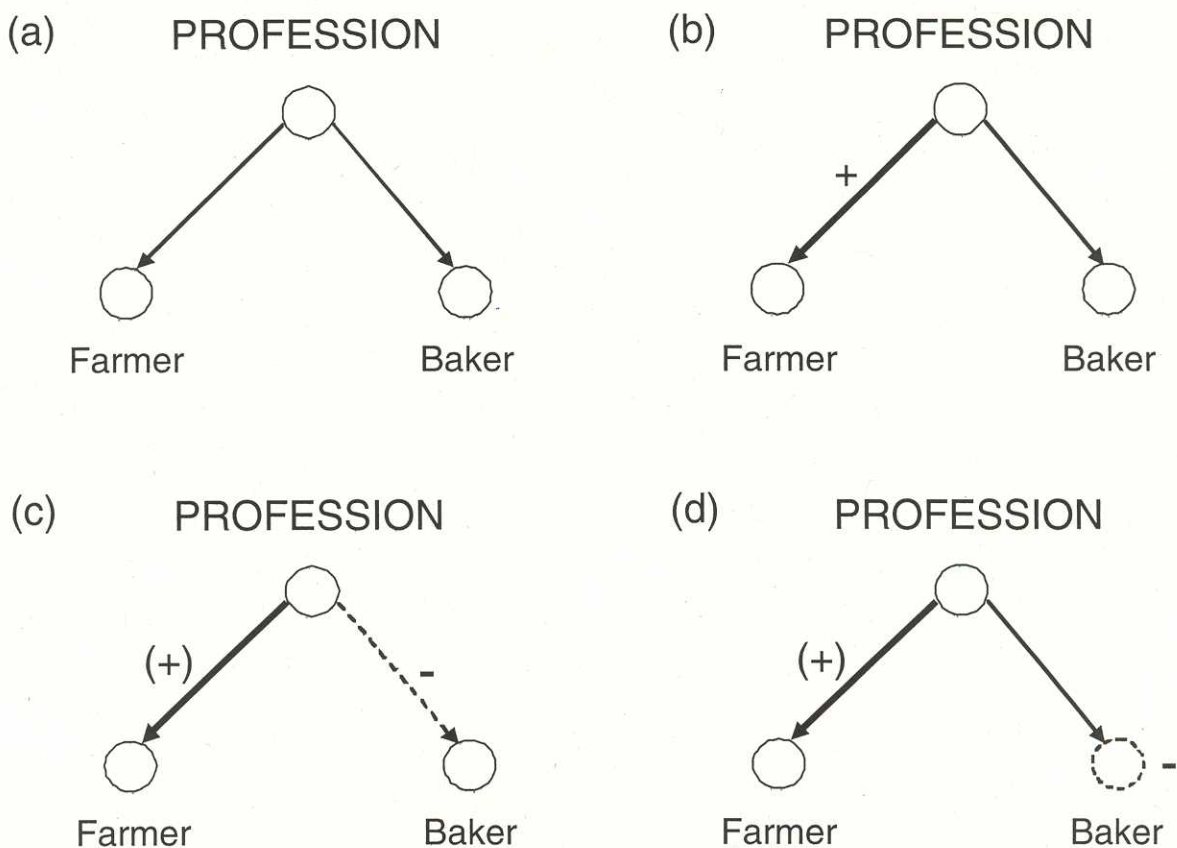


Figure 1. (a) Retrieval competition. Two items (*Farmer*, *Baker*) are connected to the same retrieval cue (*PROFESSION*) and compete for conscious recall once the cue is provided. For both materials, the competition reduces recall chances. (b) Blocking. Strengthened items (*Farmer*) block access to nonstrengthened ones (*Baker*). Blocking occurs at test when, in tendency, the strengthened material is recalled first and hinders subsequent recall of the nonstrengthened material. (c) Route deactivation. Deactivation of the retrieval route between cue and forgotten item (*Baker*; with possible simultaneous enhancement of retrieval route between cue and strengthened item, i.e., *Farmer*). Route deactivation reduces chances of the retrieval cue to make item information recoverable. (d) Item suppression. Deactivation of the memory representation of the forgotten item (*Baker*; with possible simultaneous enhancement of retrieval route between cue and strengthened item, i.e., *Farmer*). Item suppression reduces chances to recover item information regardless of which retrieval cue is provided.

Retrieval-Induced Forgetting

In 1994, a new experimental paradigm was introduced to study the detrimental effects of retrieval, the retrieval practice paradigm (Anderson, Bjork, & Bjork, 1994; Figure 2a). In this paradigm, individuals study items from different categories (e.g., *PROFESSION-Baker*, *PROFESSION-Farmer*, *DRINK-Vodka*) and repeatedly retrieve half of the items from half of the categories in a subsequent retrieval practice phase (e.g., *PROFESSION-Fa*___). After a distractor task, subjects are asked to recall the originally studied items given the category names as retrieval cues. The typical finding in this experiment is that, relative to control items from unpracticed categories (*Vodka*), recall of practiced exem-

plars (*Farmer*) is enhanced and recall of unpracticed exemplars (*Baker*) is impaired (Figure 2b).

If retrieval-induced forgetting was caused by retrieval blocking, the forgetting should disappear once item-specific probes, i.e., items' unique initial letters or their unique word stems, were employed at test. The issue was examined in experiments in which the detrimental effect of retrieval was directly compared to the detrimental effect of relearning, in which a subset of the studied material is reexposed for additional learning. Participants learned categorized lists (Figure 2a). In a subsequent practice phase, a subset of the items was relearned or retrieval practiced. At test, the category names and the targets' initial letters were provided as retrieval cues. Consistent with prior work (Bäuml, 1997), no detrimental effect of relearning arose.

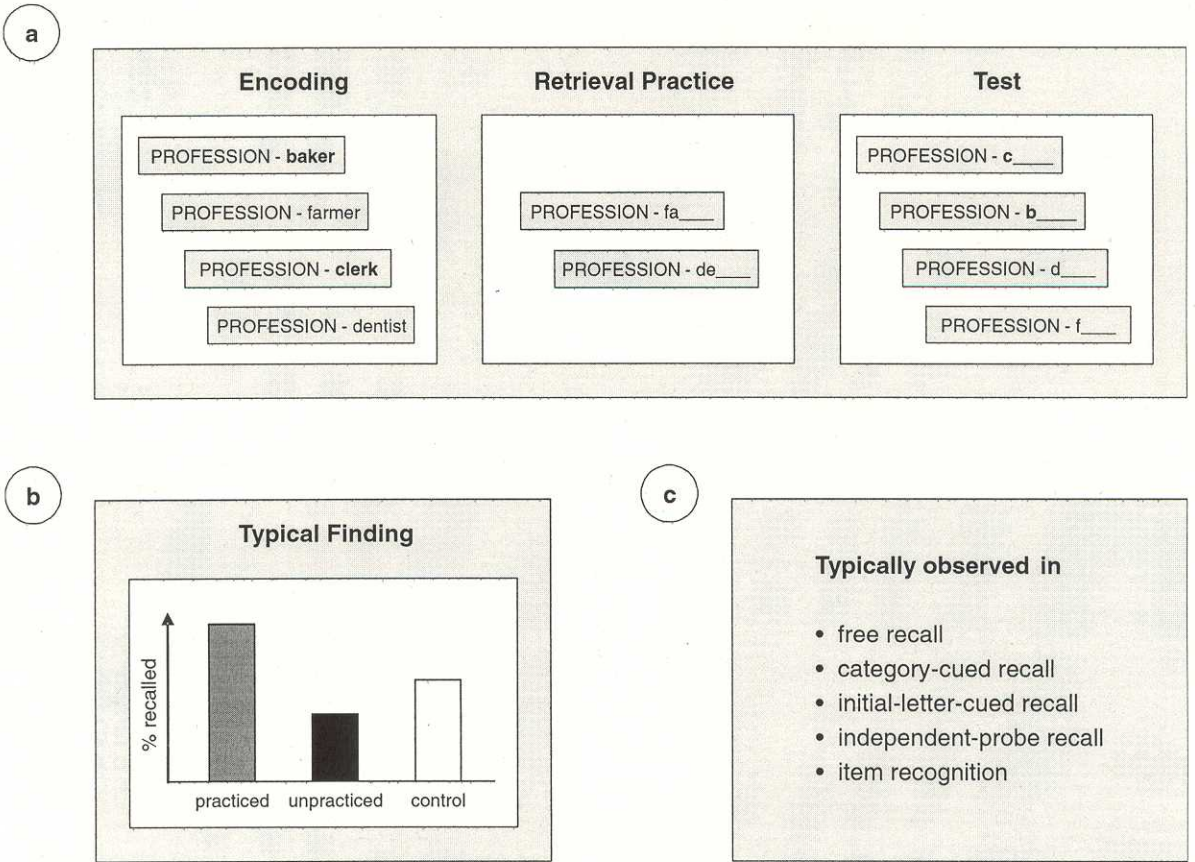


Figure 2. Retrieval-induced forgetting. (a) The experimental paradigm. Participants study a categorized item list. In a subsequent retrieval-practice phase, half of the items from half of the studied categories are repeatedly retrieved. On the final test, participants are asked to recall all previously studied items. (b) The typical finding. Practiced items show higher recall rates and unpracticed items show lower recall rates relative to the control items from the unpracticed categories. (c) Memory tests. Examples of memory tests in which retrieval-induced forgetting typically arises.

In contrast, reliable forgetting arose in the retrieval practice condition (Anderson, Bjork, & Bjork, 2000; Bäuml, 2002; Bäuml & Aslan, 2004). These findings indicate that retrieval-induced forgetting reflects a recall-specific effect. Moreover, given that the effect arises in the presence of the items' unique initial letters – and in the presence of the items' unique word stems (Anderson et al., 1994) – it indicates that the forgetting is not caused by retrieval blocking.

The proposal that retrieval-induced forgetting does not reflect blocking is further supported by studies showing that the effect is present in recognition tests (Hicks & Starns, 2004). Tulving (1985) distinguished between two bases for judging an item as *old* on a recognition test: The participant specifically remembers the temporal and/or spatial context in which the item was studied (recollection), or the participant finds the item just familiar (familiarity; for a review, see Yonelinas, 2002). In retrieval-induced forgetting, the recognition tests provided evidence that retrieval practice affects both recollective and familiarity

processes of the unpracticed material. Studies in which associative recognition was employed reported a reduction in recollective processes (Verde, 2004), studies in which item recognition was employed suggested additional reductions in familiarity processes (Spitzer & Bäuml, in press).

Using the so-called independent probe procedure, retrieval-induced forgetting has also been reported to be cue-independent, i.e., to generalize to cues other than those used at study or retrieval practice (Anderson, 2003; Anderson & Spellman, 1995). Accordingly, retrieval practice of *PROFESSION-Farmer* was found to induce forgetting of *Baker* not only when *Baker* was tested with the same cue as was used at study and retrieval practice (*PROFESSION*), but also when it was probed with a new, independent cue (e.g., *BREAD*). This finding complements the recognition findings and suggests the action of direct inhibitory processes on the forgotten items.

Indeed, the results from all these studies are consistent with the assumption of an inhibitory mechanism which di-

rectly affects the representation of the unpracticed items itself (Figure 1d). Because of such an impairment in item representation, all retrieval routes to the inhibited item should be less effective than without retrieval practice and forgetting should be observed across a wide range of memory tests. The results from the studies employing recognition tests and tests using independent probes as cues support this view and are inconsistent with the hypothesis that the inhibition is due to blocking or an effect on the retrieval routes between the inhibited item and its studied cue. Blocking is assumed to operate at test. Here the proposal is that the inhibitory mechanism operates pretest in the retrieval practice phase of the experiment. In this phase, the not-to-be-practiced material is supposed to interfere and to be inhibited to reduce the interference and make retrieval of the target information easier (Anderson & Spellman, 1995; see also Anderson, 2003).

Retrieval inhibition in retrieval-induced forgetting is supposed to reduce an item's memory strength, thus making a weak item out of an originally strong one. Response latency analysis sheds light on the dynamics of recall, allowing conclusions about the size of the underlying search set and the memory strength of the set's items (for a review, see Wixted & Rohrer, 1994). Applying such response latency analysis, Bäuml, Zellner, and Vilimek (2005) found that retrieval practice reduces unpracticed items' recall probability but does not affect their response latency. This result mirrors typical effects of item strength manipulations as they occur as a result of variations in study time or study trials (Rohrer, 1996) and is consistent with the hypothesis that retrieval practice reduces the memory strength of unpracticed items.

The inhibitory view of retrieval-induced forgetting presupposes some degree of retrieval competition and relational processing between the studied items (Figure 1a). Consistently, reliable retrieval-induced forgetting has been reported if individuals processed items in a relational way but not when they processed them in an item-specific way, i.e., by their features and distinctive qualities (Smith & Hunt, 2000; for a related result, see Bäuml & Kuhbandner, 2007). As another boundary condition of retrieval-induced forgetting, results from several studies showed that a very high degree of similarity between practiced and unpracticed items can eliminate the forgetting. In fact, if practiced and unpracticed items share a common category (FOUR-LEGGED ANIMAL) and a common subcategory (PREDATOR; i.e., *tiger, lion*) typically less forgetting arises than when they share a common category (FOUR-LEGGED ANIMAL) but not a common subcategory (i.e., *tiger, horse*; Bäuml & Hartinger, 2002; for related results see Anderson, Green, & McCulloch, 2000, or Bäuml & Kuhbandner, 2003). These findings are consistent with a variant of item suppression in which items are represented as sets of features, and features that the unpracticed item shares with the practiced one are strengthened rather than inhibited. Due to this strengthening of some of the item's features, the effect of inhibition is reduced, or even eliminated (for details, see Anderson, 2003).

The role of inhibition in cognition is of central interest in the literature on cognitive development. This is largely due to the hypothesis that young children and older adults suffer from a general deficit in inhibitory function (Bjorklund & Harnishfeger, 1990; Hasher & Zacks, 1988). Such a general deficit in inhibitory function might also apply to memory and be at the heart of the reduced memory performance of young children and older adults. However, recent results indicate that retrieval-induced forgetting is intact across most part of the lifespan. Indeed, both young children and older adults have been reported to show retrieval-induced forgetting that is equivalent in amount to that of younger adults (Aslan, Bäuml, & Pastötter, 2007; Zellner & Bäuml, 2005). These findings challenge the proposal of a general inhibitory deficit in young children and older adults and suggest that, in episodic memory, inhibitory functions may be intact for most part of the lifespan.

Part-List Cuing Impairment

Part-list cuing impairment refers to the finding that the presence of a subset of previously learned material can impair recall of the remaining noncue items (Figure 3). Part-list cuing impairment has typically been explained in terms of retrieval blocking (Roediger, 1973; Rundus, 1973). Part-list cuing, therefore, should mimic the effects of relearning, in which reexposure of a subset of studied material has been shown to block recall of the not reexposed material (Bäuml, 1997; Ratcliff, Clark, & Shiffrin, 1990). As a result, part-list cuing impairment should be restricted to tests in which no item-specific probes are provided and should disappear once item-specific probes are present.

The issue was addressed in an experiment by Bäuml and Aslan (2004). Participants learned category exemplars consisting of target and nontarget items (Figure 3a). In a subsequent phase, the nontarget items were reexposed, either for relearning or for use as retrieval cues 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. The relearning group was told to study the items further, the part-list cuing group was told to use the items as retrieval cues to recall the remaining items. At test, the category-plus-first-letter cues of the target items were presented and participants were instructed to recall the target items. As expected from the relearning literature, part-list relearning had no detrimental effect on the not reexposed target material. In contrast, part-list cuing had a detrimental effect. This held true both when the reexposure occurred immediately before test and when the reexposure was separated from test by a distractor task. This finding indicates that part-list cuing differs from relearning and that its detrimental effects are not caused by blocking. In particular, it shows that part-list cuing impairment reflects an instructional effect. Reexposure

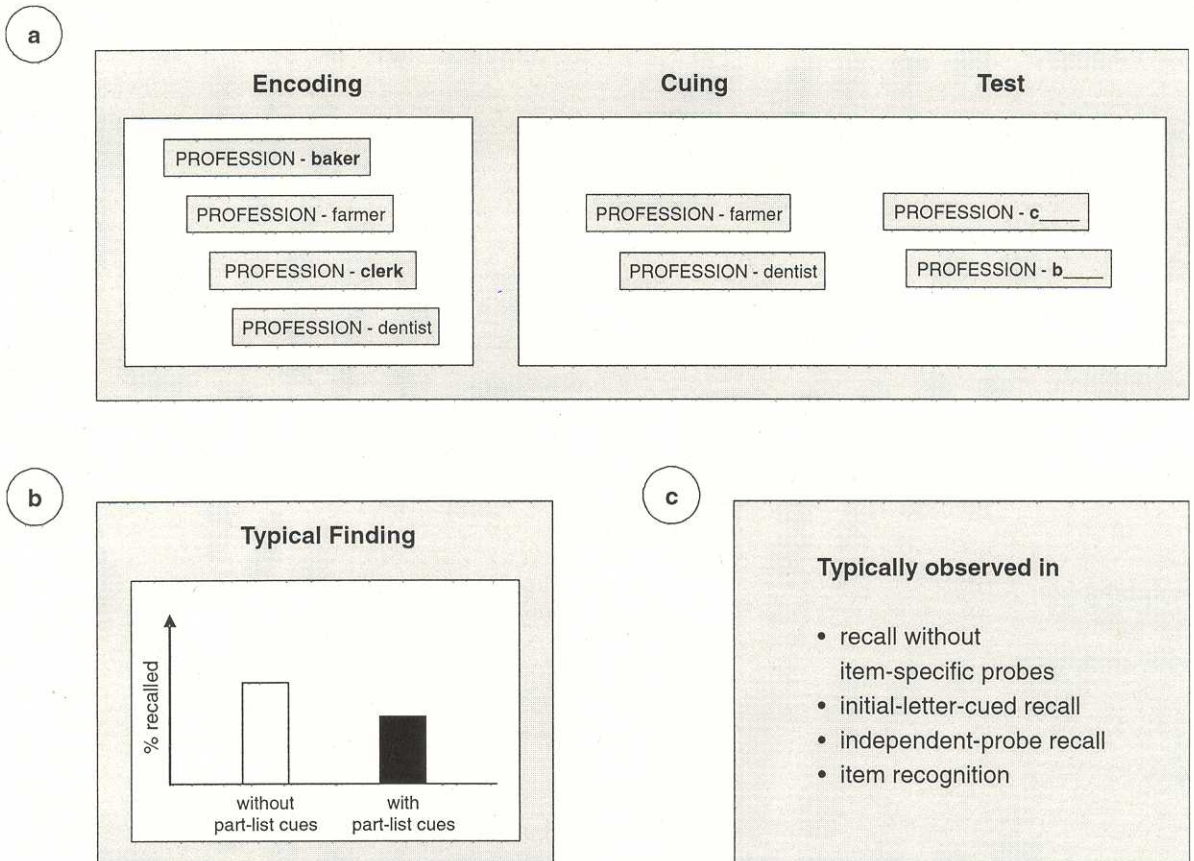


Figure 3. Part-list cuing impairment. (a) The experimental paradigm. Participants study a categorized item list. In the test phase, half of the items from half of the studied categories are presented as cues to help recalling the remaining (noncue) items. (b) The typical finding. Recall of the noncue items is lower in the presence than absence of the part-list cues. (c) Memory tests. Examples of memory tests in which part-list cuing impairment typically arises.

induces forgetting only when participants are oriented to use the reexposed items as retrieval cues.

Results from studies using other memory tests support the view that part-list cuing impairment is not caused by blocking. Reliable part-list cuing impairment was found when memory for the noncues was assessed by means of a recognition task (Todres & Watkins, 1981). Part-list cuing impairment also arose in speeded recognition (Oswald, Serra, & Krishna, 2006). Because recognition performance is assumed to rely more on familiarity than recollection when participants are required to make recognition decisions very quickly (e.g., Yonelinas, 2002), this finding suggests that part-list cuing does not only affect recollective processes but affects the familiarity of the noncue items as well.

Aslan, Bäuml, and Grundgeiger (2007) provided evidence that part-list cuing impairment is also present in recall tasks which employ independent probes. They reported a repeated-testing experiment in which, in the first test, participants were provided with part-list cues and were asked

to recall half of the noncues by presenting the items' unique initial letters. After a delay, a second test was conducted in which no part-list cues were provided and participants were asked to recall the remaining noncues by means of independent probes, i.e., probes which were not used in a previous phase of the experiment. Part-list cuing impairment was present in both tests, indicating that independent probes do not eliminate the forgetting.

The results from all these studies are consistent with the view that part-list cuing triggers inhibitory processes which directly affect the item representation of the noncues (Figure 1d). In this sense, the effect may mimic the effect of retrieval practice in retrieval-induced forgetting. Indeed, several studies compared the detrimental effects of retrieval practice and part-list cuing directly within a single experiment (Bäuml & Aslan, 2004; Bäuml & Kuhbandner, 2003; Zellner & Bäuml, 2005). In all these cases, the same qualitative and quantitative effects arose. These findings agree with the view that part-list cuing leads to instructed covert retrieval of cue items and causes inhibition of non-

cue items very similar to how overt retrieval in retrieval-induced forgetting inhibits nonretrieved items (Bäuml & Aslan, 2004).

Retrieval-induced forgetting is lasting and still present when item-specific probes are provided (Anderson et al., 1994). Consistent with the inhibitory view of part-list cuing impairment, it has also been shown that part-list cuing impairment can be lasting and be present with item-specific probes (Bäuml & Aslan, 2004, 2006). On the other hand, there are demonstrations that the cuing effect can disappear with a delay (Basden & Basden, 1995; Bäuml & Aslan, 2006) and can be absent in the presence of item-specific probes (Aslan & Bäuml, in press). Bäuml and Aslan (2006) identified encoding as a crucial factor in part-list cuing impairment. They suggested that the detrimental effect is mediated by inhibition in situations in which subjects do not encode items strategically and interitem associations play only a minor role, and that the effect is mediated by non-inhibitory mechanisms in situations in which subjects build up interitem associations and elaborated retrieval plans. In this latter case, strategy disruption appears to be the mediating mechanism. Thus, apparently more than one mechanism is involved in this form of forgetting.

From the suggestion that, at least in situations with relatively low levels of interitem associations, the detrimental effects of cuing and retrieval are mediated by the same mechanism, the prediction may be deduced that part-list cuing impairment should show a similar developmental trajectory as retrieval-induced forgetting. Zellner and Bäuml (2005) addressed the issue by comparing young children's part-list cuing impairment and retrieval-induced forgetting directly. Part-list cuing and retrieval practice induced the same detrimental effects. In particular, the detrimental effects in young children were comparable to those in younger adults. Marsh, Dolan, Balota, and Roediger (2004) examined part-list cuing in older adults. In three experiments, they found no evidence for reduced part-list cuing impairment in older adults compared to younger adults. Part-list cuing impairment, like retrieval-induced forgetting, thus seems to be intact across most part of the lifespan.

Conclusions

In prior work, the detrimental effects of retrieval and cuing were often explained in terms of retrieval blocking. As a core feature of this view, it was assumed that the forgetting in the two cases arises as a result of biased retrieval competition without affecting the forgotten material directly. The results from more recent studies challenge this picture. They show that the two forms of forgetting can be observed across a wide range of memory tests, including recognition tests and tests employing independent probes. These findings indicate that inhibitory processes mediate the two detrimental effects and that these inhibitory processes affect the forgotten items' representation directly.

In principle, retrieval inhibition does not rule out the additional involvement of retrieval blocking in retrieval-induced forgetting and part-list cuing impairment. If retrieval blocking contributed to these effects in addition to retrieval inhibition, then the detrimental effects of retrieval and cuing should be stronger in, say, category-cued recall compared to independent-probe recall. This is because in category-cued recall a higher degree of retrieval competition is expected than in independent-probe recall. To date, however, no evidence for such an interaction has been reported, suggesting that retrieval blocking plays only a minor role, if any, in these two forms of forgetting.

Tulving (1974) distinguished between an item's inaccessibility and its unavailability. Item inaccessibility refers to the case in which the representation of the item in memory is intact but the retrieval cues are ineffective, either because of increased retrieval competition or some deactivation in retrieval routes (Figure 1b, 1c). Item unavailability refers to the case in which the representation of the item itself is affected, so that memory for the item is impaired regardless of which retrieval cue is provided (Figure 1d). Following this terminology, the results on the detrimental effects of retrieval and cuing reported above indicate that retrieval-induced forgetting and part-list cuing impairment reflect item unavailability rather than item inaccessibility.

Retrieval-induced forgetting is a recall-specific effect and is mediated by the retrieval process itself (Anderson et al., 2000). Part-list cuing impairment is also assumed to be mediated by retrieval processes. Here the proposal is that the presentation of part-list cues leads to early covert retrieval (sampling) of the cue items and that this covert retrieval induces inhibition of noncue items very similar to how overt retrieval in studies on retrieval-induced forgetting induces inhibition of nonretrieved items (Bäuml & Aslan, 2004). Thus, both forms of episodic forgetting seem to be mediated by retrieval processes, which is consistent with findings showing that, in many experimental contexts, retrieval-induced forgetting and part-list cuing impairment are functionally equivalent (Bäuml & Kuhbandner, 2003; Zellner & Bäuml, 2005).

On the basis of the finding that retrieval processes mediate both retrieval-induced forgetting and part-list cuing impairment, the experimental results provide evidence that the retrieval of material can make the memories of related material unavailable. This inhibitory power of retrieval contrasts sharply with other detrimental effects in episodic memory, like effects of interference or effects of context changes, which typically affect item accessibility but not item availability (Baddeley, 1997). The detrimental effects of retrieval thus seem to reflect a particularly strong form of episodic forgetting.

As mentioned above, retrieval and cuing are not always detrimental and can also have strong beneficial effects on memory. Recently, Roediger and Karpicke (2006) demonstrated that repeatedly retrieving episodes can be highly beneficial for the practiced material and can lead to surprisingly robust memories for the practiced material over fairly

long time intervals. Also, Tulving (1974) showed that the presentation of higher-order units as retrieval cues can greatly improve recall of episodes which are associated to these units in memory. These findings indicate that retrieval and cuing show a pattern of beneficial and detrimental effects. Taking both types of effects into account is important for models of human memory as well as for applied issues, like educational settings or eyewitness testimony.

Acknowledgments

The research reported here was supported by a grant from the German Research Foundation (DFG) to Karl-Heinz Bäuml (FOR 448).

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