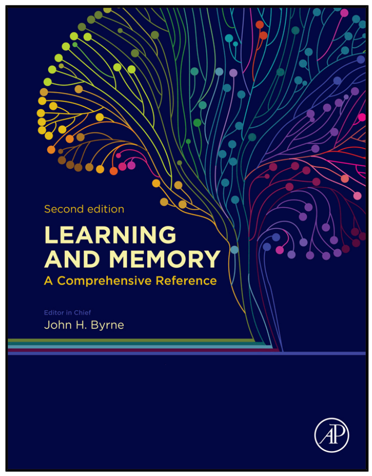

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2.03 Retrieval-Induced Remembering and Forgetting

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2.03.1 Introduction

2.03.1.1 Retrieval-Induced Remembering

Material encoded into our memory benefits from repetition. Such repetition effects can be demonstrated when, after studying a set of material, individuals get a chance to study the material again before they are tested on the study items, or when, after study, they are asked to retrieve the encoded items by themselves. In both cases, recall performance on the final test is typically higher than in a condition without any repetition opportunity (e.g., Bjork, 1975; Hogan and Kintsch, 1971).

While nearly all forms of repetition improve memory performance to some extent, there is also evidence that repetition format influences the amount of improvement. Indeed, a vast number of studies during the past decade have shown that retrieval of previously learned material can increase its long-term retention more than restudy of the information does

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(e.g., Karpicke and Roediger, 2008; Roediger and Karpicke, 2006). For instance, in their seminal study, Roediger and Karpicke had participants study prose passages and then either repeatedly retrieve or restudy the material, before they took a retention test after either a short or a long delay. When the retention test was taken after the short delay, recall of the prose passages was slightly superior in the restudy condition compared to the retrieval-practice condition, but critically, after the long delay, recall was dramatically better in the retrieval practice than in the restudy condition. This effect, sometimes referred to as the backward effect of retrieval practice (Pastötter and Bäuml, 2014), has been demonstrated over a wide range of study materials, in both lab-based studies and classroom settings (for a review, see Roediger and Butler, 2011).

There are further benefits of retrieval practice, and retrieval practice in comparison to restudy, for instance, can induce better transfer of the study material or improve organization of newly acquired knowledge (see Roediger et al., 2011). A particularly striking further benefit, which Pastötter and Bäuml (2014) termed the forward effect of retrieval practice, is the finding that retrieval practice of previously studied material can increase long-term retention of subsequently studied material (e.g., Pastötter et al., 2011; Szpunar et al., 2008). Szpunar et al. (2008), for instance, had their participants study five word lists in anticipation of a final cumulative recall test. Between the study of each pair of lists, participants solved math problems, restudied the words from the most recent list, or were engaged in retrieval practice on these items. After study of all five lists, participants were asked to recall the words from the final critical list 5. Results showed that participants who were engaged in retrieval practice on lists 1–4 recalled more items of list 5 and showed fewer prior-list intrusions than the participants in the two no-retrieval-practice conditions, indicating that interpolated retrieval practice can reduce interference from previously studied material. Again, the effect was demonstrated over a wide range of study materials and settings (for a review, see Pastötter and Bäuml, 2014).

All these findings suggest that retrieval practice is a very powerful tool to enhance long-term retention. However, an important common characteristic of all these studies on retrieval-practice effects is that participants were asked to practice retrieval of *all* the initially studied items, which contrasts with many everyday life situations in which, either intentionally or unintentionally, only *some* of the originally encoded episodes are retrieved. Such selective retrieval may take place during a conversation with a colleague about some detail of an earlier business meeting, when a student prepares for an upcoming exam and due to time restrictions repeats a subset of the learned material only, or when a person is interrogated by a police officer about a specific event that he or she witnessed a few days ago. There is good reason to expect that selective retrieval induces similar beneficial effects on the selectively retrieved information as retrieval does for the retrieved material when practice is nonselective. However, it is less clear whether selective retrieval will also affect later memory of the nonretrieved material, i.e., the details not mentioned in the conversation with the colleague, the material not repeated by the student before the exam, and the events not addressed by the police officer when interrogating the witness. Arguably, selective retrieval may not influence memory of the nonretrieved material, given that this material was not subject to any repetition at all. But, as this chapter will show, typically selective retrieval does influence recall of other nonretrieved memories.

2.03.1.2 Retrieval-Induced Forgetting

Casual subjective experience may suggest that selective retrieval can improve recall of nonretrieved memories. For instance, when talking with a former classmate about times past, remembering a particular event from the high-school days sometimes initiates a chain of retrieval processes, along which more and more of the seemingly forgotten memory is being recollected. Similarly, when trying to recall details of a previous vacation, retrieval of a first few details may reactivate other details and thus help reconstructing the original event. The spreading activation models of memory, which were very influential in the 1960s and 1970s, support such intuition, suggesting that activation of a specific memory content facilitates activation of related contents (Collins and Loftus, 1975). In addition, there is evidence from eyewitness memory research that active retrieval of some previously experienced events can benefit memory of other events (Geiselman et al., 1985). In contrast, experimental work during the past decades has often failed to find empirical support for the view that selective retrieval improves recall of other contents. Rather, such studies typically reported that selective retrieval impairs memory of other information. Evidence for such retrieval-induced forgetting (RIF) has arisen mainly from two experimental tasks: the older output-interference task and the more recent retrieval-practice task.

During the past 20 years, RIF has mostly been examined with the retrieval-practice task, which was introduced into the literature by Anderson et al. (1994). In this task, a subset of previously studied material is repeatedly retrieved and the effect of this manipulation on later recall of the practiced and unpracticed material is examined, in comparison to appropriate control conditions. For instance, participants may study several items from different semantic categories (e.g., FRUIT-*banana*, FRUIT-*orange*, FRUIT-*apple*, FRUIT-*guava*) before, in a subsequent retrieval-practice phase, they are asked to repeatedly retrieve half of the items from each of the single categories (e.g., FRUIT-*or*___, FRUIT-*gu*___; *retrieval-practice condition*), or perform an unrelated distractor task instead (*control condition*). After a delay, participants are then asked to recall all initially studied items (see **Fig. 1A**). As expected, recall of the practiced items (e.g., *orange*) is typically improved on the final test, relative to recall of the items in the control condition. However, recall of the unpracticed items from the practiced categories (e.g., *banana*) is affected as well. In contrast to the practiced items, recall of these items is impaired relative to the control items, which reflects the RIF finding (**Fig. 1C**; see also Shaw et al., 1995).

In the 1960s and 1970s, effects of selective retrieval on recall of other items were first examined employing the output-interference task, in which it was investigated how recall of studied items varies as a function of the items' serial position in the testing sequence. The typical finding was that recall success declined with the items' testing position (Smith, 1971; Tulving and

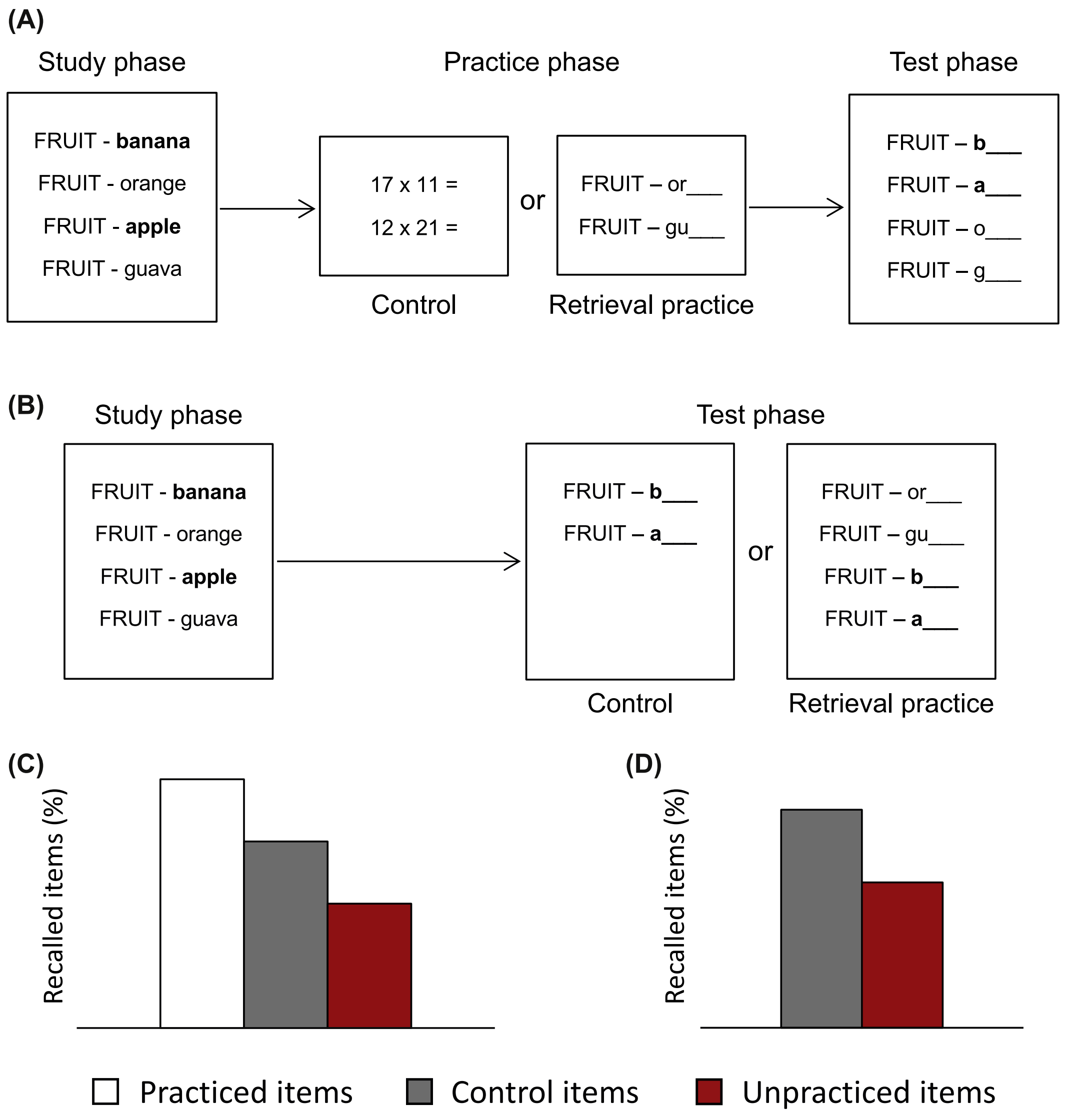

Figure 1 (A) The retrieval-practice task as applied to semantically categorized lists. In the study phase, participants study several items from different semantic categories. At test, they are asked to recall predefined target words (in *bold*) from each single category (e.g., *banana*, *apple*), providing the words' category name and unique initial letters as retrieval cues. Recall of the target words occurs with or without selective retrieval of the category's remaining nontarget items (e.g., *orange*, *guava*) during the preceding practice phase. At test, participants are again asked to recall the (practiced) nontarget items. (B) The output-order task as applied to semantically categorized lists. In the study phase, participants study several items from different semantic categories. At test, memory of predefined target items (in *bold*) from each single category is assessed (e.g., *banana*, *apple*), providing the words' category name and unique initial letters as retrieval cues. Recall of the targets occurs either with or without preceding selective retrieval of the category's remaining nontarget items (e.g., *orange*, *guava*). (C) Typical finding: retrieval-practice task. Practiced items show higher recall rates and unpracticed items show lower recall rates relative to the control items in the control condition, in which no retrieval practice occurred. (D) Typical finding: output-order task. Preceding selective retrieval of the nontarget items reduces recall of the target items ("unpracticed items") relative to the control condition, in which preceding nontarget recall is absent ("control items").

Arbuckle, 1963), which is consistent with the finding of RIF in the retrieval-practice task. In a later variant of the task, which is closer to the retrieval-practice task (and is more neutrally termed the output-order task in the following), participants may again study items from different semantic categories (e.g., FRUIT-*banana*, FRUIT-*orange*, FRUIT-*apple*, FRUIT-*guava*) before, in the final test phase, they are asked to recall a predefined half of a category's items first or after selective retrieval of the category's other items (**Fig. 1B**). Recall is typically impaired if other items from the same category were previously retrieved (e.g., Anderson et al., 1994; Bäuml, 1998; see **Fig. 1D**), which again demonstrates RIF.

RIF is a very general phenomenon. It has been observed in a variety of study materials, such as visuospatial materials (Ciranni and Shimamura, 1999), text passages (Chan et al., 2006), or autobiographical material (Barnier et al., 2004), and in numerous experimental settings. For instance, Shaw et al. (1995) examined the impact of repeated questioning of a witness on memories that were not subject to the interrogation. Participants were shown slides depicting the aftermath of a theft and were subsequently asked several times to recall selected details of what they saw. Similar to what happened with other settings of the retrieval-practice task, the typical pattern of beneficial and detrimental effects of repeated interrogation was present in participants' later recall of crime scene details, suggesting that, also in such simulated legal context, RIF may arise. In a series of experiments, RIF has even been shown to arise in social groups. In these studies, pairs of individuals studied a list of items and subsequently one member of the pair (the "speaker") selectively retrieved some of the items, whereas the other member (the "listener") listened to the speaker's responses, monitoring their accuracy. When the listener was subsequently asked to recall the remaining items, memory of these items was impaired (for a review, see Hirst and Echterhoff, 2012).

The fact that RIF generalizes to such a variety of materials and situations is of potential relevance in everyday life. Indeed, because retrieval will be selective in numerous (if not most) everyday situations, there is reason to expect that, quite often, retrieval will cause a pattern of benefits and costs in our memory, with recall of the (selectively) retrieved material being enhanced and recall of the nonretrieved material being impaired. Thus during the conversation with the colleague, if only some of the topics of an earlier business meeting were discussed, memory of these topics may have been enhanced, whereas forgetting of the remaining topics may have been induced. Or when the student practiced only some of the course material that was relevant to the exam, the practiced material may have been easily accessed during the exam but recall of the remaining course material may have been impaired.

This chapter investigates the costs of such selective retrieval, i.e., RIF, in more detail. It addresses the cognitive mechanisms underlying the RIF effect (see the section Mechanisms), the role of testing format for the effect (see the section Testing Format), the question of whether RIF is retrieval specific (see the section Retrieval Specificity) and whether it is interference dependent (see the section Interference Dependence), and the role of retention interval between selective retrieval and test for the effect (see the section Persistence of Retrieval Practice Effects). Finally, the issues will be raised whether there may also be conditions under which selective retrieval may improve memory of the nonretrieved information (see the section When Selective Retrieval Improves Recall of Other Items) and whether there are individual differences in the effects of selective retrieval (see the section Individual Differences). The chapter will end by drawing some more general conclusions on the effects of selective retrieval.

2.03.2 Mechanisms

2.03.2.1 Retrieval-Induced Remembering

As mentioned in the previous section, both selective and nonselective retrieval practice promote subsequent recall of the practiced material. In both cases, these effects may be attributed to simple strengthening of the practiced items. For nonselective retrieval practice, this assumption is indeed a core element of the bifurcation model of the effects of nonselective retrieval practice, which, in essence, suggests that the memory representations of successfully retrieved items are strengthened to a higher degree than the memory representations of restudied items. Combined with the idea that retrieval practice bifurcates the strength distributions of successfully and unsuccessfully retrieved items, this model can explain a diverse set of findings on the beneficial effects of nonselective retrieval practice (for details, see Halamish and Bjork, 2011; Kornell et al., 2011). With regard to selective retrieval practice, it is also often assumed that the selectively retrieved items are strengthened (e.g., Anderson et al., 1994), but besides this basic idea, there are typically no detailed elaborations on this point of view (for an exception, see Raaijmakers and Jakab, 2012).

Other accounts of nonselective retrieval-practice effects offer more specific ideas about the cognitive mechanisms underlying the improvement effect, such as the elaborative retrieval account (Carpenter, 2009) or the episodic context account (Karpicke et al., 2014). The elaborative retrieval account assumes that when individuals attempt to retrieve a previously studied item from memory, semantically related memory representations are coactivated during the search for the item, and this semantic elaboration during initial retrieval can improve recall on a later retention test. The episodic context account assumes that during retrieval of a previously studied item, the context representation associated with that item may be updated such that it includes a composite of the features of both the (unique) study and the (unique) retrieval context of the particular item. Serving as effective retrieval cues on a later memory test, these contextual features may then improve later recall of the practiced items. Each of these accounts can explain many findings on the beneficial effects of retrieval practice, although none of them seems to be able to explain the full range of results (see Rowland, 2014). However, because the mechanisms proposed in the two accounts are not mutually exclusive, they may conjointly contribute to the wide range of beneficial effects of retrieval practice.

2.03.2.2 Retrieval-Induced Forgetting

Selective retrieval not only improves recall of the practiced material but also impairs recall of the unpracticed items. The two most prominent accounts to explain this forgetting are the inhibition account and the blocking account. The inhibition account proposes that in the retrieval-practice task, RIF arises as a consequence of the necessity to overcome retrieval competition during the retrieval-practice phase (Anderson, 2003). This account, which partly has its roots in the older response-set suppression hypothesis (Postman et al., 1968), assumes that when a subset of the studied items are retrieval practiced (e.g., *orange*), the not-to-be-practiced items (e.g., *banana*) interfere and compete for conscious recall. To reduce the interference and facilitate selection of the to-be-practiced items, the memory representation of the not-to-be-practiced items becomes suppressed, leading to weakened representations of these

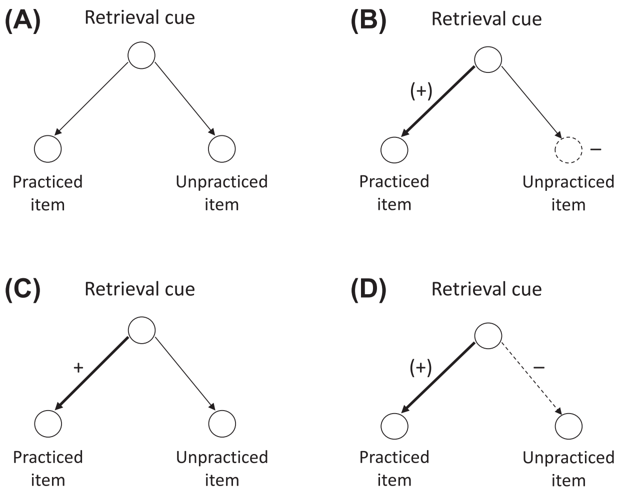

Figure 2 (A) Retrieval competition. The practiced item (e.g., *orange*) and the unpracticed item (e.g., *banana*) are connected to the same retrieval cue (e.g., FRUIT) and compete for conscious recall once the cue is provided. (B) Inhibition account. Selective retrieval deactivates the memory representation of the unpracticed item (with possible simultaneous enhancement of the cue–item association of the practiced item). The deactivation takes place during selective retrieval and reduces chances to recover the unpracticed item, regardless of which retrieval cue is provided. (C) Blocking account. Selective retrieval strengthens the cue–item association of the practiced item. At test, the (strengthened) practiced item then blocks access to the (nonstrengthened) unpracticed item. Blocking does not affect the unpracticed item's association with its retrieval cue and does not affect its memory representation. (D) Context account. Selective retrieval induces a shift in internal context, so that at test, the association between the retrieval cue and the unpracticed item is weakened and recall chances for the unpracticed item are reduced. Like blocking, context change does not affect the memory representation of the unpracticed item itself.

items and impaired recall on a later memory test (see Fig. 2B). The inhibition account can also explain RIF as it arises in the output-interference and output-order tasks by assuming that at test, the yet-to-be-recalled items (e.g., *banana*) interfere during preceding selective retrieval (e.g., *orange*) and are inhibited to reduce the interference.

The blocking account was the original explanation of RIF as it arises in the output-interference task (Roediger and Neely, 1982). The account, which was partly inspired by McGeoch's (1942) response competition theory of interference, can explain RIF in this task by assuming that preceding recall of some items at test (e.g., *orange*) strengthens the memory representations of those items and thus blocks recall of the remaining items (e.g., *banana*) because of increased interference from the recalled items. Blocking can also account for RIF as it arises in the retrieval-practice task (Raaijmakers and Jakab, 2013; Verde, 2013). Here the critical assumption is that retrieval practice strengthens the associations between the practiced items (e.g., *orange*) and their category cues, and such strengthening leads to blocking of the (not strengthened) unpracticed items (e.g., *banana*) at test, thus creating RIF (see Fig. 2C).

Another noninhibitory, but context-based, account has been suggested to explain RIF (Jonker et al., 2013). This account was inspired by models of episodic memory that assume a critical role for context in memory (e.g., Mensink and Raaijmakers, 1988; Polyn et al., 2009) and, in particular, a body of research demonstrating that retrieval can result in internal context shifts (e.g., Jang and Huber, 2008; Pastötter et al., 2011). At its core, this account assumes that retrieval practice introduces a shift in participant's internal context, creating distinct study and practice contexts. Control categories are therefore encountered in the study phase only, whereas retrieval-practice categories are encountered in both the study and the retrieval-practice contexts. Critically, at test, participants are then assumed to inappropriately access the more recent practice context when searching for the (practiced categories') unpracticed items, but access the study context when searching for the control items. As a result, recall of the unpracticed items may be impaired relative to the control items and RIF may arise (see Fig. 2D).

The following sections will report many findings from the RIF literature and, within each section, the question will be raised of which of the results can be explained by each of the single accounts. Notably, all three accounts of RIF constitute single-mechanism accounts, meaning that they attempt to explain RIF on the basis of a single distinct mechanism. As it will turn out, however, none of the single mechanisms seem to be able to explain the full range of RIF findings. In a few places in this chapter, we will therefore ask whether a combination of the, mutually nonexclusive, suggested mechanisms may provide a better explanation of RIF findings than is provided by assuming that a single mechanism mediates the RIF effect (e.g., see the section Retrieval Specificity). Doing so, we will also raise the question of whether selective retrieval may trigger further mechanisms, which may then enhance, rather than reduce, recall of other memories (e.g., see the section When Selective Retrieval Improves Recall of Other Items).

2.03.3 Testing Format

Beneficial effects of nonselective retrieval on the retrieved items were found for a variety of testing formats, such as free recall, cued recall, and item recognition (see Rowland, 2014). Analogous results arose for the effects of selective retrieval on the practiced items (e.g., Murayama et al., 2014), which were consistent with the expectation that selective and nonselective retrieval should induce similar beneficial effects on the retrieved items (see the section Mechanisms). Thus regarding the role of testing format for the effects of selective retrieval, the more interesting question is which testing formats reveal RIF. Single accounts of RIF make quite different predictions on the issue, for instance, with one account suggesting that the effect should be present over a wide range of testing formats and another account suggesting that it should be present mainly with free and some forms of cued recall. This section addresses this important issue, asking the questions of whether RIF arises in (1) different forms of recall tests, (2) item recognition tests, and (3) implicit memory tests.

2.03.3.1 Recall Tests

The effects of selective retrieval practice on the unpracticed items were examined with quite different forms of recall tests. Anderson et al. (1994), for instance, showed that RIF in the retrieval-practice task is present with category-cued recall. In this testing format, participants are provided with the category cues of the previously studied items as retrieval cues (e.g., FRUIT) and are asked to recall all studied exemplars from that particular category in any order they prefer. Using this type of test to measure RIF, however, comes with the disadvantage that participants may start their recall of the category exemplars with the previously strengthened practiced items (*orange*, *guava*), which may then reduce recall of the unpracticed items (*banana*, *apple*) because of the output interference at test. If so, it remains unclear whether, as suggested by the inhibition account, RIF in the retrieval-practice task arises because of inhibition operating during retrieval practice.

To reduce such output-interference effects, researchers tried to get some control over the participants' output order of a category's items by employing category-plus-stem-cued recall tests. With this testing format, participants are provided the category cues of studied items together with the items' unique initial letters (FRUIT-*b*___). Moreover, participants are always asked to recall a category's unpracticed items first and the practiced items last. Doing so, again in many studies reliable RIF arose (e.g., Murayama et al., 2014; see **Fig. 3A**), supporting the view that RIF in the retrieval-practice task does not just reflect output-order effects at test.

The finding that RIF arises with category-plus-stem-cued recall tests is well in line with the inhibition and context accounts of RIF. The inhibition account predicts that retrieval practice reduces the strength of unpracticed items and recall of these items should therefore be reduced in all forms of recall tests. The context account predicts that retrieval practice induces context shift and such shifts are typically observable in recall tests. In contrast, the finding of RIF with category-plus-stem-cued recall tests appears inconsistent with blocking because arguably control of output order should reduce, if not eliminate, possible blocking effects at test. Although there is indeed evidence that control of output order can reduce blocking effects at test (e.g., Bäuml, 1998), over

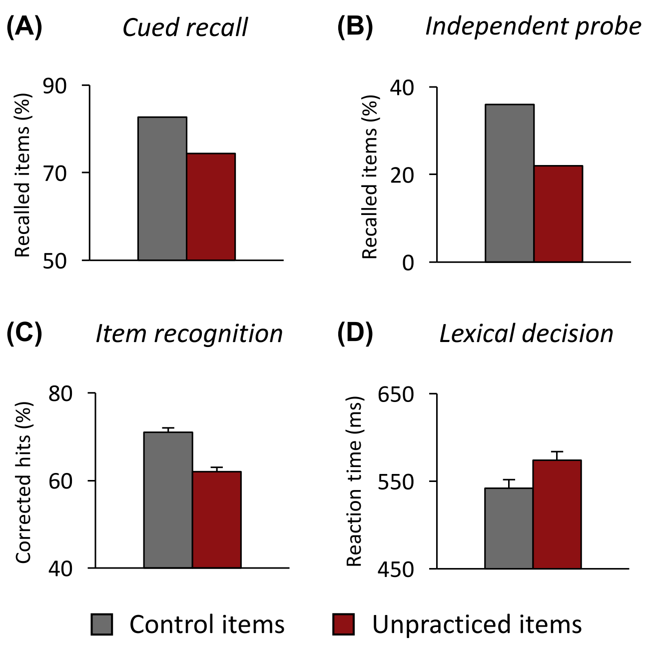

Figure 3 Detrimental effects of selective retrieval on unpracticed items in different testing formats. (A) Category-plus-stem-cued recall. (B) Independent probe testing. (C) Item recognition. (D) Lexical decision making. Error bars represent standard errors. Adapted from (A) Anderson, M.C., Bjork, R.A., Bjork, E.L., 1994. Remembering can cause forgetting: retrieval dynamics in long-term memory. J. Exp. Psychol. Learn. Mem. Cogn. 20, 1063–1087; (B) Anderson, M.C., Spellman, B.A., 1995. On the status of inhibitory mechanisms in cognition: memory retrieval as a model case. Psychol. Rev. 102, 68–100; (C) Hicks, J.L., Starns, J.J., 2004. Retrieval-induced forgetting occurs in tests of item recognition. Psychon. Bull. Rev. 11, 125–130; (D) Veling, H., van Knippenberg, A., 2004. Remembering can cause inhibition: retrieval-induced inhibition as cue independent process. J. Exp. Psychol. Learn. Mem. Cogn. 30, 315–318.

the years, it turned out to be somewhat unclear whether and when such control eliminates blocking effects completely (see the section Retrieval Specificity). Other testing formats may therefore be more suitable to evaluate the single RIF accounts.

2.03.3.2 Cue Independence

Because both category-cued recall and category-plus-stem-cued recall leave open the possibility that blocking effects may contribute to RIF, researchers were particularly interested in recall tests that may completely eliminate possible blocking effects. To reach this goal, Anderson and Spellman (1995) introduced the so-called independent probe procedure to study RIF effects. With this procedure, the items from the original study list (e.g., *banana*) are not tested with their original study cue (FRUIT) but with a novel test cue (YELLOW), which unlike the original study cue should not easily coactivate the category's practiced items (e.g., *orange*) and thus should eliminate possible blocking effects from the practiced items at test. If so, this form of testing would be suitable to disentangle the putative effects of inhibition, blocking, and context change for RIF.

According to the inhibition account, RIF should arise regardless of whether, during the final test, participants' memory for a particular item is assessed with the category label that was presented during study or with a novel test cue that was not present at study or during the retrieval-practice phase. The reason is that after study of FRUIT-*orange* and FRUIT-*banana*, the retrieval practice of *orange* should weaken the memory representation of *banana* and recall of *banana* should be impaired irrespective of which type of cue was provided for recall of the item. In contrast, providing independent probes at test should eliminate any blocking effects because novel cues (YELLOW) should generally prevent practiced items (*orange*) from interfering with the recall of the unpracticed items (*banana*), and thus no RIF should arise. RIF should also be cue dependent on the basis of the context account because novel cues should eliminate the suggested context effects and thus eliminate RIF.

Over the years, quite a number of studies examined cue independence of RIF. The results of a first line of such studies provided evidence in support of the proposed property. They consistently reported that the memory of unpracticed items was worse than the memory of control items when novel retrieval cues were employed at test (Anderson and Bell, 2001; Anderson and Spellman, 1995; Aslan et al., 2007; Saunders and MacLeod, 2006; see **Fig. 3B**), which was seen as specific support for the inhibition account of RIF.

Some follow-up studies, however, questioned the diagnostic role of cue independence in inferring inhibition, arguing that the independent probe method may not provide a pure measure of inhibition. According to the self-inflicted blocking hypothesis, participants may use covert cuing during the final test. Covert cuing refers to a participant's use of retrieval cues that are not explicitly provided at test (Camp et al., 2009). For instance, in the retrieval-practice task, it may be possible that participants use the originally studied category (e.g., FRUIT) as an internal retrieval cue to access a given exemplar (e.g., *strawberry*) during the final test, even though they are only cued with an independent probe (e.g., RED), thus inducing blocking at test. Camp et al. did not study covert cuing in the retrieval-practice task, but they provided evidence that covert cuing can arise in the context of a paired-associate learning task. In this task, there was an initial study phase in which participants were shown a subset of cue items (e.g., ROPE) that were subsequently studied together with a target item in a second study phase (e.g., ROPE-*sailing*, SUNFLOWER-*yellow*). Then in the test phase, an extralist category cue (e.g., SPORTS, COLOR) was presented and participants were instructed to recall an item from the study list that was an exemplar of that category (e.g., *sailing*, *yellow*). Previous study of the paired-associate cue item (e.g., ROPE) improved extralist category cued recall, even though this item was not presented at test.

Weller et al. (2013) responded to Camp et al. (2009) in a study that employed a retrieval-practice task with a final independent probe test. In particular, at test, an independent probe appeared with the target item's two initial letters (e.g., YELLOW-*ba*___) and was followed briefly by the studied category for that target (e.g., FRUIT). The rationale behind this procedure was that overtly showing the original category cue shortly after the independent probe would mimic the category retrieval that the self-inflicted blocking hypothesis claims causes RIF on independent probe tests. However, in contrast to this proposal, flashing the original category cue decreased RIF, rather than increasing it, which challenges the view that RIF, as measured with independent probe testing, is the result of blocking induced by covert cuing processes. Overall, these results indicate that RIF is indeed cue independent, which supports the inhibition account but challenges the blocking and context accounts of RIF.

2.03.3.3 Item Recognition

RIF has also been examined using item recognition. Examining RIF in item recognition is interesting for at least two reasons. One reason is that many types of episodic forgetting (e.g., interference effects, context effects) arise primarily in recall tests but are often absent, or at least reduced, in item recognition. Another reason is that RIF accounts differ in whether they predict RIF in item recognition.

According to the inhibition account, retrieval practice reduces unpracticed items' memory representation, and the detrimental effect of practice should therefore be observable in item recognition. In contrast, RIF should not arise in item recognition if RIF was caused by blocking. Indeed, although there is evidence that certain types of interference, such as retroactive interference or the list-length effect, may show up in item recognition (e.g., Chandler, 1989; Ratcliff et al., 1990), there is also evidence that strength-based interference effects do not easily generalize from recall to item recognition. For instance, the list-strength effect—the demonstration that restudy of a subset of studied items can impair memory of the not restudied material—is usually absent in item recognition (e.g., Ratcliff et al., 1990; Shiffrin et al., 1990), a finding well captured by models of recognition memory (e.g., Shiffrin and Steyvers, 1997). The expectation may thus arise that strength-based blocking effects in the retrieval-practice task are also restricted to recall and RIF will not generalize to item recognition.

On the basis of the context account, it is less clear whether RIF should arise in item recognition because some context effects have been shown to be present in recognition, whereas other context effects are absent. Still Jonker et al. (2013) argued that the context account would predict RIF in item recognition when the recognition test is not speeded and the distractors are difficult to distinguish from the targets, which they assume to be the case when semantically categorized lists are employed as study material. The proposal then is that when the studied item *banana* is presented at test without its category label, participants may covertly retrieve the category label FRUIT and make use of the context associated with that category in their retrieval attempt. According to the context account, the most relevant and accessible context in the case of practiced categories will then be the practice context, which will create contextual mismatch for the unpracticed items and thus induce RIF.

Most studies on RIF in item recognition used nonspeeded yes/no recognition tests. These studies typically analyzed the proportion of correctly recognized target items (that is, the hit rate) and the proportion of incorrectly recognized lure items (that is, the false alarm rate), and on the basis of these measures, they computed the corrected hit rates, which are calculated by subtracting the false alarm rate from the hit rate to measure recognition accuracy. Doing so, the studies typically found reduced recognition of the unpracticed items relative to the control items, thus demonstrating RIF in item recognition (e.g., Aslan and Bäuml, 2010; Hicks and Starns, 2004; Román et al., 2009; see **Fig. 3C**).

Also by employing nonspeeded recognition tests, some prior studies analyzed participants' receiver operating characteristic (ROC) curves at test, which yields a richer source of information on item recognition than simple yes–no tests (see Macmillan and Creelman, 2005). In these studies, a final recognition test was administered in which each of the old and new items was presented together with a 6-point rating scale, and participants rated their confidence of an item having been previously studied (old) or not (new) on that scale (e.g., $1 =$ definitely old, $6 =$ definitely new). The ROC curve is then obtained by cumulating the hit and false alarm rates across the rating scale starting at the most confident criterion, i.e., definitely old (1), thus relating hits and false alarm rates across variations in response criteria (i.e., the propensity to make a positive recognition response). The results from these analyses supported the findings from the yes–no recognition studies by showing RIF with ROC curves (Dobler and Bäuml, 2013; Rupprecht and Bäuml, 2016; Spitzer and Bäuml, 2007). This is held regardless of how exactly the ROC curves were analyzed, without any additional modeling of the data (e.g., Rupprecht and Bäuml, 2016), when modeling the data using the unequal-variance signal detection model (e.g., Rupprecht and Bäuml, 2016; Spitzer and Bäuml, 2007) or the dual-process models of item recognition (e.g., Spitzer and Bäuml, 2007).

To date, only two studies examined RIF using speeded yes/no recognition tests. Knowing whether RIF is present in this form of tests is theoretically relevant because by asking participants to react as quickly as possible to presented items, such tests may measure inhibition more directly than that occurs with nonspeeded item recognition. Arguably, presenting participants with the items themselves may preempt the active retrieval process, and the resulting response latencies may be a more direct indication of the activation level of the items (Veling and van Knippenberg, 2004). However, the results of the studies are mixed. Veling and van Knippenberg indeed found that recognition response latencies were slower for unpracticed than control items, suggesting that RIF (or rather, retrieval-induced slowing) is present with speeded recognition, whereas Verde and Perfect (2011) did not find an effect in response latencies. Although it is thus not yet clear whether RIF is present in speeded item recognition, overall there is strong evidence that RIF is present in nonspeeded item recognition. This finding challenges the blocking account of RIF but is consistent with the inhibition account and may also be reconciled with the context account of RIF (but see the section Retrieval Specificity).

2.03.3.4 Implicit Tests

So far, all the studies addressed in this section have examined RIF employing explicit memory tests, i.e., tests in which participants are asked to recall or recognize previously studied material. However, RIF was also assessed with implicit memory tests, i.e., tests that do not require participants to deliberately or consciously recollect previously studied material (Schacter, 1987). Examining whether RIF arises in implicit tests is empirically important because, like with item recognition, forgetting effects, as they may arise due to interference or context change, are often absent in implicit tests. Examining whether RIF arises in implicit tests is also theoretically important because the presence of RIF in such tests would strongly support the view that retrieval practice reduces items' memory representation, which would be consistent with inhibition but would challenge the blocking and context accounts of RIF.

Veling and van Knippenberg (2004) employed a lexical decision task to address the issue. Participants studied a categorized list of words (e.g., FRUIT-*banana*, FRUIT-*orange*, PROFESSION-*teacher*) and performed retrieval practice on a subset of the items from a subset of the studied categories (e.g., FRUIT-*or*___). Then, at test, participants were presented with letter strings and were asked to indicate as quickly as possible for each single string whether it was a word or nonword. Importantly, some of the letter strings were items from the earlier study phase, both unpracticed and control items (e.g., *banana*, *teacher*). If retrieval practice reduced unpracticed items' memory representation, as is suggested by the inhibition account, such reduction should slow the response process and the response times for unpracticed items should be higher than those for control items. Consistent with this expectation, the word/nonword judgments were indeed found to be slower for unpracticed items (e.g., *banana*) than for control items (e.g., *teacher*), thus demonstrating RIF (see **Fig. 3D**). Bajo et al. (2006) employed a different type of implicit test in which fragment cues not presented during the study and practice phases (e.g., __*gative* for *Negative*) were used, and participants were asked to complete the fragments with the first word that came to their mind. Again the results showed reliable RIF. Although some further implicit tests were also shown to impair recall of unpracticed items, such as category generation or category matching (see Murayama et al., 2014), there is also evidence that not all forms of implicit tests may induce RIF (see Perfect et al., 2002).

2.03.3.5 Summary

The results of the studies reported in this section show that RIF arises in many testing formats, including category-cued recall, category-plus-stem-cued recall, independent probe testing, and item recognition. RIF has even been reported for some implicit testing formats, such as lexical decision making. These findings are consistent with the inhibition account of RIF, which predicts RIF to arise over a wide range of memory tests. In contrast, the findings challenge the blocking account, which predicts RIF to be absent with independent probe testing, item recognition, and implicit memory tests. The findings also challenge the context account of RIF, according to which RIF should not arise with independent probe testing and implicit memory tests.

2.03.4 Retrieval Specificity

Effects of nonselective retrieval practice on the practiced items are typically larger than the effects of nonselective restudy trials. With regard to the backward effect of retrieval practice, this has been demonstrated numerous times, but mainly for longer retention intervals (e.g., Karpicke and Roediger, 2008; Roediger and Karpicke, 2006; see the section Introduction). With regard to the forward effect of retrieval practice, it has been shown that beneficial effects of repetition on subsequently studied material arise only after intermittent retrieval, but not after intermittent restudy trials, indicating that the forward effect of nonselective retrieval is even retrieval specific (e.g., Pastötter et al., 2011; Szpunar et al., 2008; see the section Introduction). Against this background, the question arises whether the detrimental effects of selective retrieval practice are also generally stronger than those of selective restudy, or are even retrieval specific. Retrieval specificity of RIF would mean that forgetting of the unpracticed items requires preceding selective retrieval of the practiced items, whereas preceding selective restudy would not induce any forgetting of the unpracticed items.

The blocking account of RIF suggests that the forgetting of unpracticed items is not restricted to retrieval practice but, in principle, can arise after any kind of strengthening of the cue–item associations of the practiced items, whereas the inhibition account assumes that the forgetting is retrieval specific. According to this view, retrieval practice, but not restudy of the practiced items, should induce interference and inhibition of the unpracticed items during practice and thus impair memory of the unpracticed items at test. The context account also suggests retrieval specificity because retrieval, but not restudy, should induce context change during the practice phase and thus induce RIF. However, in contrast to the inhibition account, this account predicts that all forms of retrieval practice should induce RIF, regardless of whether retrieval practice is competitive or not. In addition, all forms of induced context change should induce RIF-like forgetting (see later discussion).

2.03.4.1 Examining Retrieval Specificity With Recall Testing

Two methods have originally been employed to examine retrieval specificity of RIF: restudy and noncompetitive retrieval practice. In both methods, the to-be-practiced items are reexposed intact with the goal of strengthening the items' associations to their cue without inducing interference and inhibition of unpracticed items. When employing the restudy method, some of the originally studied category–item pairs were reexposed (e.g., FRUIT-*orange*) and participants were instructed to study the word pairs once again. When employing the noncompetitive retrieval-practice method, some of the originally studied items were reexposed and participants were asked to recall the items' category label given the label's word stem as a retrieval cue (e.g., FR___-*orange*). Using category-plus-stem-cued recall at test, the results of numerous studies showed forgetting of unpracticed items after standard (competitive) retrieval practice, but no forgetting after restudy cycles (e.g., Bäuml, 2002; Bäuml and Aslan, 2004; Ciranni and Shimamura, 1999; see **Fig. 4A**) and no forgetting after noncompetitive retrieval practice (e.g., Anderson et al., 2000a; Ferreira et al., 2014; Hanslmayr et al., 2010). These findings are consistent with retrieval specificity, supporting the inhibition account but challenging the blocking account of RIF. The restudy results are also consistent with the context account, whereas the results for noncompetitive retrieval are not.

These previous findings may not necessarily contradict the blocking account of RIF because reexposure format may be critical for whether restudy induces forgetting or not. Arguably, plain reexposure may not induce forgetting of the unpracticed items because it may strengthen the representation of the practiced items without strengthening the items' associations to the cue, which may not be sufficient to cause blocking at test (e.g., Raaijmakers and Jakab, 2012; Verde, 2013). Thus RIF may no longer be found to be retrieval specific if retrieval practice was compared to restudy formats that, like retrieval practice is supposed to do, enhance the cue–item associations of the practiced items. In such case, forgetting of the unpracticed items may arise after both retrieval practice and restudy, which would be consistent with the blocking view of RIF.

Results of two studies support such view. Employing a modification of the original noncompetitive retrieval-practice condition, Raaijmakers and Jakab (2012) had participants study category–exemplar pairs (e.g., ROUND-*ball*) and asked the participants in the practice phase to recall a pair's category label presenting the exemplar as a retrieval cue (e.g., ____-*ball*). In contrast to the original design by Anderson et al. (2000a), the word stems of the category labels were not presented as retrieval cues and items of relatively low frequency within their categories were employed, conditions that likely make noncompetitive retrieval practice more demanding than in the original studies. Doing so, Raaijmakers and Jakab found reduced recall of the unpracticed items after noncompetitive retrieval practice, indicating that the strengthening of the category–exemplar associations can be sufficient to induce RIF. In the second study, Verde (2013) employed a modification of the original restudy condition, testing the hypothesis that

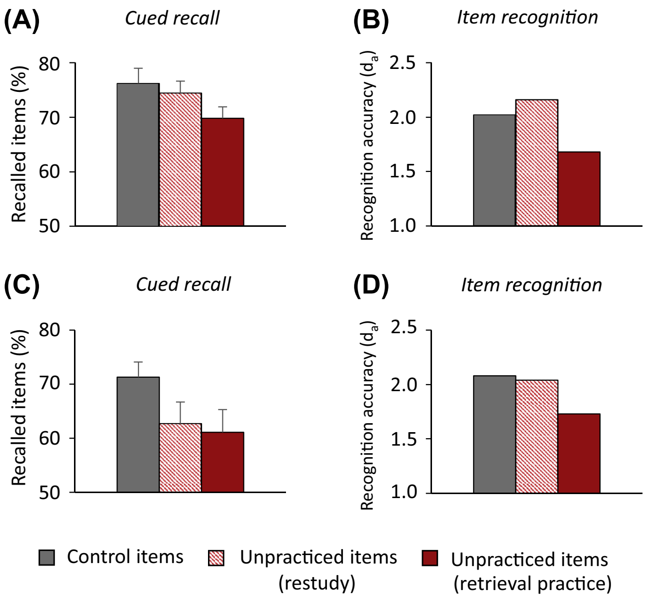

Figure 4 Comparison of the effects of selective retrieval and selective restudy on unpracticed items' cued recall and item recognition. (A) Selective retrieval, but not (standard) selective restudy, impaired recall of the unpracticed items. (B) Selective retrieval, but not (standard) selective restudy, impaired recognition of the unpracticed items. (C) Both selective retrieval and selective restudy supplemented with pleasantness ratings impaired recall of the unpracticed items. (D) Selective retrieval, but not selective restudy supplemented with pleasantness ratings, impaired recognition of the unpracticed items. d_a, estimate of recognition accuracy using the unequal-variance signal detection model. Error bars represent standard errors. Adapted from (A) Dobler, I.M., Bäuml, K.-H.T., 2013. Retrieval-induced forgetting: dynamic effects between retrieval and restudy trials when practice is mixed. Mem. Cogn. 41, 547–557; (B) Dobler, I.M., Bäuml, K.-H.T., 2013. Retrieval-induced forgetting: dynamic effects between retrieval and restudy trials when practice is mixed. Mem. Cogn. 41, 547–557; (C) Rupprecht, J., Bäuml, K.-H.T., 2016. Retrieval-induced forgetting in item recognition: retrieval specificity revisited. J. Mem. Lang. 86, 97–118; (D) Rupprecht, J., Bäuml, K.-H.T., 2016. Retrieval-induced forgetting in item recognition: retrieval specificity revisited. J. Mem. Lang. 86, 97–118.

reexposure formats that strengthen category–item associations can induce forgetting similar to how retrieval practice does. Participants, for instance, learned category–item pairs and were then asked at practice to rate the pleasantness of the reexposed item in the presence of the item's category cue. Such reexposure reduced recall of the unpracticed items at test, indicating that retrieval may not be necessary to induce RIF and restudy formats that enhance the cue–item associations of the practiced items can be sufficient to cause RIF-like forgetting. The findings from both studies are consistent with the blocking account, whereas they disagree with inhibition. The findings from the second study also disagree with the context account because pleasantness ratings should not induce context change.

2.03.4.2 Examining Retrieval Specificity With Item Recognition Testing

With these findings the question arises whether the results reported by Raaijmakers and Jakab (2012) or Verde (2013) are restricted to recall testing or generalize to other testing formats. Indeed, as explained in the section Testing Format, RIF is not a pure recall phenomenon and can also be found in other testing formats, such as item recognition. Thus if RIF was not retrieval specific, not only standard (competitive) retrieval practice but also noncompetitive retrieval practice and restudy when supplemented with pleasantness ratings should reduce recognition of the unpracticed items.

Addressing the first prediction, Grundgeiger (2014) compared the effects of competitive retrieval practice with the effects of noncompetitive retrieval practice, with both recall and item recognition. As expected, he found both competitive and noncompetitive selective retrieval to reduce recall of unpracticed items. In contrast, however, he found reduced recognition after competitive but not after noncompetitive retrieval practice. Rupprecht and Bäuml (2016) replicated the finding and additionally compared the effects of competitive retrieval with the effects of restudy when supplemented with pleasantness ratings, with both recall and item recognition. Again they found both forms of practice to reduce recall of unpracticed items, whereas they found retrieval only to reduce recognition of the unpracticed items (see Fig. 4C and D). These findings demonstrate retrieval specificity of RIF and thus challenge the blocking account of RIF. Moreover, by showing that the effects of competitive retrieval but not the effects of noncompetitive retrieval create RIF in item recognition, they also challenge the context account of RIF.

The findings of a study by Rupprecht and Bäuml (2017) provide another challenge to the context account by showing that induced context change is not sufficient to create RIF-like forgetting. The study compared the effects of competitive retrieval practice with the effects of restudy preceded by context change, with both recall and item recognition. Context change was induced by an imagination task and a semantic generation task, both of which are well known to be able to change participants' internal states (Jang and Huber, 2008; Pastötter and Bäuml, 2007; Pastötter et al., 2011; Sahakyan and Kelley, 2002). Consistent with the prior RIF work, retrieval practice was found to reduce both recall and item recognition of the unpracticed items. In contrast, restudy preceded by context change reduced recall of the unpracticed items, which replicated prior work by Jonker et al. (2013), but left recognition of the unpracticed items unaffected. The finding challenges the context account of RIF by indicating that induced context change does not create RIF-like forgetting in item recognition. Rather, it is consistent with inhibition by indicating that retrieval is necessary to induce forgetting of the unpracticed items.

2.03.4.3 Explaining the Retrieval Specificity Findings

As is obvious from the sections Examining Retrieval Specificity With Recall Testing and Examining Retrieval Specificity With Item Recognition Testing, none of the three accounts of RIF can explain the whole range of findings from the retrieval specificity studies. Therefore, Rupprecht and Bäuml (2016) suggested a two-factor account to explain the results. According to this account, both inhibition and blocking may contribute to RIF: inhibition may operate during retrieval practice and, in addition, blocking may arise during the final test. Importantly, inhibition is supposed to induce a retrieval-specific reduction in the unpracticed items' memory representation, which is observable over a wide range of memory tests, whereas blocking is proposed to play a role primarily in tests, in which item-specific cues are reduced, and to be largely absent in item recognition, in which the items themselves are presented as cues. Consequently, even though both inhibition and blocking may contribute to RIF in general, the particular test format should influence the relative contribution of the two mechanisms (for similar ideas, see Anderson and Levy, 2007; Aslan and Bäuml, 2010; Bäuml, 2008; Grundgeiger, 2014; Storm and Levy, 2012).

This two-factor account is consistent with the retrieval specificity findings reported in this section. It agrees with (1) the observed presence of RIF in both recall and item recognition, (2) the presence of RIF-like forgetting after certain restudy formats in recall but not in item recognition, and (3) the presence of RIF-like forgetting after certain forms of noncompetitive retrieval practice in recall but not in item recognition. In fact, because both restudy and noncompetitive retrieval should induce blocking but not inhibition, they may create RIF-like forgetting in recall but not in item recognition; in contrast, because competitive retrieval should induce both blocking and inhibition, RIF should arise in both forms of memory tests.

The two-factor account can also explain the pattern of RIF-like forgetting after restudy preceded by context change, attributing the effect to blocking processes. Because there is evidence that, after context change, item encoding can be improved (Pastötter et al., 2008, 2011), restudy preceded by context change may enhance the strengthening of the associations of the items to their category label, induce blocking at test, and thus create RIF-like forgetting in recall (Rupprecht and Bäuml, 2017). The absence of the effect in item recognition agrees with this blocking explanation because blocking effects do not seem to show up in item recognition (e.g., Ratcliff et al., 1990; Rupprecht and Bäuml, 2016). The two-factor account is also consistent with a wide range of other RIF findings (for a more detailed discussion, see Rupprecht and Bäuml, 2016).

2.03.4.4 Summary

The results of the studies reported in this section show that selective (competitive) retrieval impairs both recall and recognition of unpracticed items. In contrast, the effects of some forms of selective restudy and the effects of selective noncompetitive retrieval may be present in recall, but they do not arise in item recognition. At least with item recognition, RIF is thus retrieval specific. As a whole, the findings challenge all current single-mechanism accounts of RIF as full explanations of RIF. However, they can be explained by a two-factor account, which assigns a role for both inhibition and blocking in RIF.

2.03.5 Interference Dependence

The inhibition account of RIF predicts not only that RIF should arise over a wide range of memory tests (see the section Testing Format) and that it should be retrieval specific (see the section Retrieval Specificity) but also that RIF should be interference dependent. Indeed, because inhibition is assumed to be initiated to resolve competition during retrieval practice, unpracticed items that interfere strongly during retrieval practice of a target item should be subject to more inhibition than unpracticed items that interfere weakly, or not at all. For example, if, while practicing the retrieval of *orange* in response to FRUIT, the word *strawberry* readily comes to mind, it will create strong interference and a need for inhibitory control. In contrast, the word *guava* will likely not come strongly to mind in response to the retrieval cue and therefore will create less interference and end up being less inhibited. As a result, the amount of RIF should vary with unpracticed items' interference potential. The following sections summarize the results of studies that examined the issue.

2.03.5.1 Manipulating the Strength of Unpracticed Items

The first experiment addressing interference dependence of RIF was reported by Anderson et al. (1994). Using the retrieval-practice task, these researchers varied studied unpracticed items' strength in memory by manipulating the taxonomic frequency of the items, employing either items of high taxonomic frequency (e.g., for the category FRUIT, *orange* and *strawberry*) or items of low taxonomic

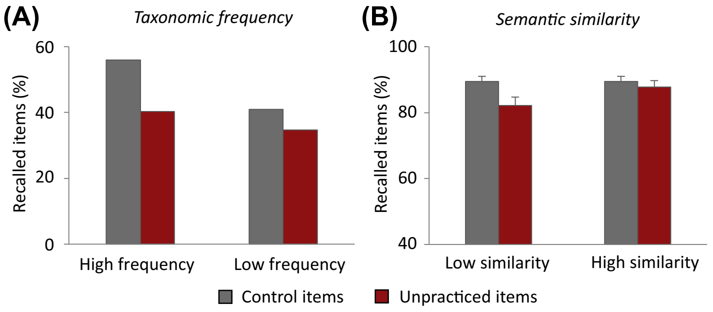

Figure 5 Effects of selective retrieval on unpracticed items as a function of unpracticed items' taxonomic frequency and the semantic similarity between practiced and unpracticed items. (A) RIF was more pronounced for unpracticed items of high taxonomic frequency than those of low taxonomic frequency. (B) RIF was more pronounced for unpracticed items with low semantic similarity than those with high semantic similarity to the practiced items. Error bars represent standard errors. Adapted from (A) Anderson, M.C., Bjork, R.A., Bjork, E.L., 1994. Remembering can cause forgetting: retrieval dynamics in long-term memory. J. Exp. Psychol. Learn. Mem. Cogn. 20, 1063–1087; (B) Bäuml, K.-H.T., Hartinger, A., 2002. On the role of item similarity in retrieval-induced forgetting. Memory 10, 215–224.

frequency (e.g., *guava* and *kiwi*). Selective retrieval practice caused RIF primarily when the unpracticed items were high in taxonomic frequency, whereas no reliable RIF arose for the low-frequency items (see Fig. 5A), which is consistent with interference dependence. Bäuml (1998) replicated the finding using the output-order task.

Storm et al. (2007) tested interference dependence of RIF by manipulating the strength of competing items via a directed forgetting instruction, in which participants after study of a list of items were asked to either remember the studied items for an upcoming test or forget the items because they would not be tested later (e.g., Bjork, 1989). The authors found that items from lists that participants were asked to keep in mind exhibited more RIF than did items from lists that participants were told to forget. This finding is consistent with interference dependence because to-be-remembered items should interfere more strongly during selective retrieval than to-be-forgotten items and thus should show more RIF (for related results, see Bäuml and Samenieh, 2010, or Little et al., 2011; for diverging results when using category-cued recall, see Jakab and Raaijmakers, 2009).

Shivde and Anderson (2011) used the so-called concurrent-probe paradigm to examine interference dependence. This paradigm includes two apparently independent tasks that participants perform simultaneously. One task is that participants are asked to keep in mind the meaning of a target word (e.g., *angry*) to indicate whether its meaning matched the meaning of a probe word (e.g., *mad*) that is presented after a retention interval. The other task is that participants perform a lexical decision task, which takes place either during the retention interval or after the participants' response to the memory probe. Results showed that reaction times in the lexical decision task were slowed for words semantically related to the target item that they were asked to maintain (e.g., *yell*), thus basically showing RIF (or rather, retrieval-induced slowing) and indicating that a competing target item's semantic representation can be weakened if the item's activated semantic representation interferes with task performance. These results, which represent a more general case of RIF via sustained attention, are also consistent with interference dependence.

2.03.5.2 Manipulating Unpracticed Items' Relational Processing

Other work tested interference dependence of RIF by manipulating the relational processing of study items. Relational processing was manipulated by varying either the strength of the episodic associations between single items or the preexperimental (semantic) associations between the items. Manipulating the strength of the episodic associations, Anderson et al. (2000b) found that RIF was absent when participants studied items from different semantic categories and, in a subsequent phase, were asked to generate similarities among a category's practiced and unpracticed items. In contrast, RIF still arose in a condition in which participants were asked to generate similarities between single unpracticed items. This finding is consistent with interference dependence, suggesting that when practiced and unpracticed items are episodically integrated and interference between the two item types is thereby reduced, RIF can be eliminated.

Bäuml and Hartinger (2002) varied the preexperimental (semantic) associations between single studied items by manipulating whether the unpracticed items (e.g., ANIMAL PREDATOR-*Tiger*) came from the same subcategory (PREDATOR) as the practiced items (ANIMAL PREDATOR-*Lion*) or were drawn from a different subcategory (e.g., HOOFED ANIMAL, such as ANIMAL HOOFED ANIMAL-*Horse*). Participants studied a categorized list, with each category consisting of two subcategories with two exemplars each. During retrieval practice, participants retrieved one item from each practiced category. RIF was absent when practiced and unpracticed items showed a very high degree of semantic similarity (i.e., same category and same subcategory), whereas RIF was present when the degree of similarity was reduced (i.e., same category but different subcategory; see Fig. 5B; for similar results, see Goodmon and Anderson, 2011). Overall, these findings suggest that RIF can be eliminated when there are strong (semantic or episodic) associations between practiced and unpracticed items, which supports interference dependence and the assumption of a critical role of inhibition in RIF.

2.03.5.3 Manipulating Unpracticed Items' Item-Specific Processing

There is also evidence that not only high levels of relational processing but also high levels of item-specific processing can eliminate RIF. Smith and Hunt (2000), for instance, found that RIF was absent when participants were presented with items from different semantic categories and, in a subsequent phase of the experiment, were asked to generate differences among the items of a category. Relative to a standard encoding task, they found a reduction, and even elimination, of the RIF effect. On the basis of these results, Smith and Hunt argued that a certain level of similarity is a precondition for RIF to occur. According to this view, similarity is associated with competition, whereas distinctive processing of items may reduce the competition and thus reduce RIF.

Further evidence for the view that item-specific processing can reduce RIF comes from a study that examined the effects of mood on RIF. Negative moods have been argued to influence memory performance by encouraging item-specific processing (e.g., Storbeck and Clore, 2005). Because item-specific processing may reduce interference between items (see earlier discussion), on the basis of the inhibition account of RIF and the interference dependence property, there is thus reason to expect that RIF is reduced, if not eliminated, in negative moods. Addressing the issue, Bäuml and Kuhbandner (2007) induced positive or negative moods in participants immediately before the retrieval-practice phase by showing participants positively or negatively valenced pictures. While typical enhancement effects of selective retrieval practice were observed for practiced items, regardless of moods, forgetting of unpracticed items arose in the positive-mood condition but not in the negative-mood condition, which supports the view of interference dependence of RIF.

In a recent study, Kliegl and Bäuml (2016) used another way to enhance item-specific processing of unpracticed items. They examined whether *nonselective* retrieval practice when interpolated between the study phase and the *selective* retrieval-practice phase can reduce RIF. The expectation that nonselective retrieval practice may reduce RIF arises from the episodic context account of nonselective retrieval-practice effects (Karpicke et al., 2014), according to which nonselective retrieval can reduce interference between items by creating distinct and item-specific context features for the retrieved items (see the section Mechanisms). The results were indeed consistent with this view, showing that when study of an item list was followed by a nonselective restudy cycle, subsequent selective retrieval induced the standard RIF effect. In contrast, when study of the list was followed by a nonselective retrieval cycle, subsequent selective retrieval did not induce any RIF effect. The finding arose when using both the retrieval-practice task and the output-order task.

2.03.5.4 Manipulating When Unpracticed Items Are Encoded

While the studies reported in the previous sections examined interference dependence of RIF by varying the strength or the relational and item-specific processing of the unpracticed items, Chan et al. (2015) examined interference dependence without manipulating single features of the items. Rather, in their study, it was manipulated when in the retrieval-practice task the unpracticed items are encoded. Concretely, the question was raised whether RIF depends on when unpracticed items are encoded before retrieval practice starts or whether RIF is also present when unpracticed items are encoded after retrieval practice of the practiced items.

The study employed a version of the retrieval-practice task, in which four study blocks and four retrieval-practice blocks are interspersed, instead of having a single retrieval-practice block after a single study block. Specifically, in the first study block, participants studied 25% of the to-be-learned category–exemplar pairs. This was followed immediately by the first retrieval-practice block, during which participants practiced retrieval on some of the studied items. This study-plus-practice cycle was then repeated three more times with a different set of materials for each cycle. Using this design, it was possible to manipulate whether retrieval of the practiced items occurred before or after the unpracticed items were encoded. RIF was found to be absent when retrieval of the practiced items took place *before* the study of the unpracticed items, whereas RIF was present when retrieval practice occurred *after* study of the unpracticed items. These results suggest that forgetting of unpracticed items arises only when these items have the opportunity to interfere during retrieval practice. The finding supports interference dependence and the proposal of a critical role of inhibition in RIF.

2.03.5.5 Summary

The results of the studies reported in this section show that RIF is interference dependent. Manipulating the interference potential of unpracticed items during selective retrieval can affect the magnitude of the subsequent forgetting, and reduce, or even eliminate, RIF when unpracticed items' interference potential is low. These results are consistent with inhibition. They cannot be attributed to blocking, which generally predicts no such interference dependence (Raaijmakers and Jakab, 2013), and they are not easily reconciled with context change (Chan et al., 2015). They thus support the previous view of a critical role of inhibition in RIF.

2.03.6 Persistence of Retrieval Practice Effects

Nonselective retrieval practice generally leads to higher recall for practiced items than nonselective restudy of the same material (see the section Introduction). This effect of retrieval practice typically increases with the length of the retention interval between practice and test. In fact, the numerical difference between the two forms of practice can be small, nonexistent, or even reversed when a short retention interval of only a few minutes separates practice from test, whereas a fairly large numerical difference can arise when the retention interval is increased to hours or even days (e.g., Carpenter, 2009; Kornell et al., 2011; Roediger and Karpicke, 2006). The reason is that retrieved items are relatively immune against time-dependent forgetting, whereas restudied items show time-dependent forgetting quite similar to that shown by not repeated (control) items. All current accounts of this effect of retrieval practice can explain this pattern, attributing it to the effects of elaboration, enriched contextual encoding, or differences in strength distributions between retrieved and restudied items (see the section Mechanisms).

Effects of nonselective retrieval practice for the practiced items also increase relative to the effects of nonselective restudy when after practice new information is encoded that is related to the originally studied items. Typically, such interpolated new learning induces retroactive interference at test and thus reduces recall performance (e.g., Müller and Pilzecker, 1900). However, it seems to affect restudied items more than retrieval-practiced items, so that the effect of retrieval practice is typically larger in the presence than the absence of new learning between practice and test (e.g., Bäuml et al., 2014; Halamish and Bjork, 2011; Potts and Shanks, 2012). The finding that nonselective retrieval practice can reduce the susceptibility of memories to interference has been explained through enhanced list segregation processes, arguing that nonselective retrieval practice may help distinguishing retrieved information from other nonretrieved information (Bäuml and Kliegl, 2013; Halamish and Bjork, 2011).

On the basis of these results on the roles of length of retention interval and interpolated learning for the effects of nonselective retrieval practice, the question arises which role the two factors play for the effects of selective retrieval practice. One may expect that for the practiced items, the results for nonselective retrieval practice generalize to the effects of selective retrieval practice, so that the effect of selective retrieval on recall of the practiced items increases with the length of the retention interval and increases when the retention interval is filled with the learning of new information. Abel and Bäuml (2014) were able to confirm both expectations, demonstrating that compared to control items, practiced items show less forgetting when the retention interval is prolonged (for similar findings see Abel and Bäuml, 2012, or Chan, 2009, but see MacLeod and Macrae, 2001, for diverging results) and show less forgetting when there is interpolated learning during the retention interval.

Expectations on the role of length of retention interval and interpolated learning for the RIF effect are less clear. Some researchers have argued that, for instance, the inhibition account predicts that RIF reflects temporary forgetting, expecting it to be diminished or even eliminated after a delay (e.g., MacLeod and Macrae, 2001), whereas others have argued that inhibition may have persisting consequences (e.g., Storm et al., 2012). Clear-cut expectations are also difficult on the basis of the blocking and context change accounts, although again there may be reason to expect some dissipation of the RIF effect with delay (e.g., Divis and Benjamin, 2014; Mensink and Raaijmakers, 1988). With regard to the possible role of interpolated learning for the RIF effect a similar picture arises (see Abel and Bäuml, 2014).

2.03.6.1 The Role of Length of Retention Interval for Retrieval-Practice Effects

Although most RIF studies in the literature used retention intervals of 5 min or less between practice and test, some studies used longer retention intervals of 20 min, 24 h, or even several days between practice and test. The studies that used retention intervals of 20 min (e.g., Anderson et al., 1994; Anderson and Spellman, 1995; Chan, 2009) reported effect sizes of RIF quite similar to those reported in the studies with shorter retention intervals, indicating that the size of the RIF effect may not show much change within the first 20 min between practice and test.

The studies that used retention intervals of 24 h between practice and test compared RIF after such prolonged retention interval with RIF after a short baseline interval of a few minutes. Many of these studies reported intact RIF after the short delay but no RIF after the long delay (Abel and Bäuml, 2014; Carroll et al., 2007; Chan, 2009; MacLeod and Macrae, 2001; Saunders and MacLeod, 2002). Typically, these studies showed normal time-dependent forgetting for the control items but hardly any time-dependent forgetting for the unpracticed items, which made the RIF effect disappear. Some other studies suggested that RIF may well persist after a delay of 24 h (Migueles and García-Bajos, 2007; Saunders et al., 2009; Storm et al., 2006). However, these studies used a repeated-test design in which participants were given an initial test shortly after retrieval practice and were then tested on the same items 24 h later. Unfortunately, because on the initial test more control items than unpracticed items were recalled, and because recall of an item can enhance its recall on a subsequent test (e.g., Roediger and Karpicke, 2006), the RIF effect found after the prolonged retention interval may have been caused by the recall difference in the initial test.

Two studies used a retention interval of 7 days between practice and test (Garcia-Bajos et al., 2009; Storm et al., 2012). They reported significant RIF, indicating that RIF can still arise after a very long delay between practice and test. This result first of all contrasts with the many failures to find RIF after retention intervals of 24 h. However, like the studies employing the 24-h retention interval, the Storm et al. (2012) study showed numerically stronger time-dependent forgetting for the control items than the unpracticed items. Although the presence of RIF after longer delay may thus depend on the details of the experimental task, as a whole, the results seem to converge on the view that the RIF effect decreases with increasing delay, with more time-dependent forgetting for the control items than the unpracticed items. The role of retention interval for the unpracticed items, therefore, is remarkably parallel to the role of retention interval for the practiced items, both after selective and nonselective retrieval practice (see earlier discussion).

Retention intervals of 24 h and more typically include nocturnal sleep. Because sleep is assumed to consolidate memories (for a review, see Diekelmann and Born, 2010), the question arises whether sleep may affect the RIF effect, showing different consolidation effects for unpracticed and control items. Two studies addressed the issue, examining RIF after two 12-h delay conditions: one filled with wake activity and the other filled with nocturnal sleep (Abel and Bäuml, 2012; Racsmány et al., 2010). In the wake condition, participants studied and practiced the material in the morning, whereas in the sleep condition, study

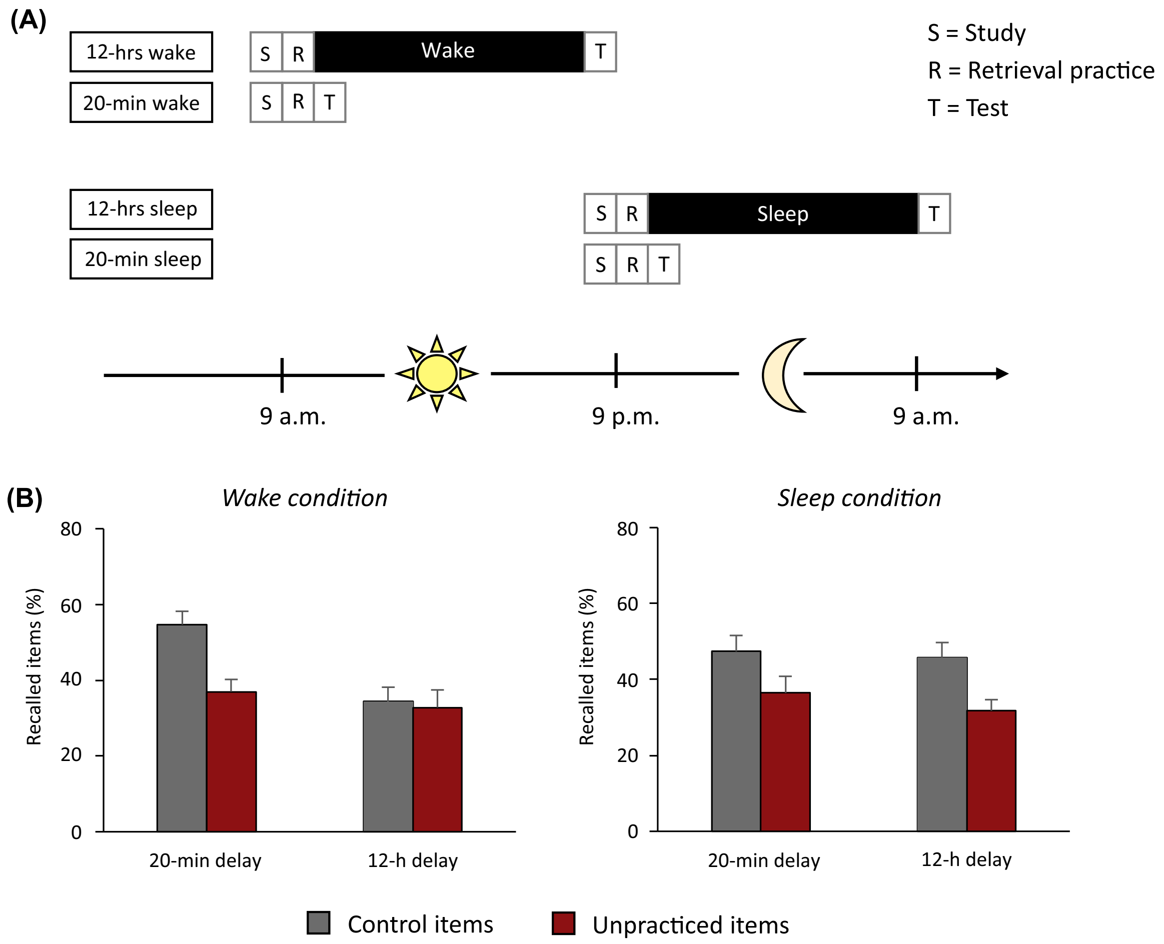

Figure 6 Effects of selective retrieval on unpracticed items as a function of wake and sleep delay between practice and test. (A) Procedure. Participants started the experiment at 9 a.m. (20-min wake and 12-h wake conditions) or 9 p.m. (20-min sleep and 12-h sleep conditions) and completed the experiment after 20 min (20-min wake and 20-min sleep conditions) or with a delay of 12 h (12-h wake and 12-h sleep conditions). (B) Results. RIF was present after short delay and after the 12-h sleep delay, whereas it was absent after the 12-h wake delay. Error bars represent standard errors. *R*, retrieval practice; *S*, study; *T*, test. Adapted from Abel, M., Bäuml, K.-H.T., 2012. Retrieval-induced forgetting, delay, and sleep. Memory 20, 420–428.

and practice occurred in the evening (see Fig. 6A). Both studies reported no RIF effect after the wake delay, thus replicating the results of the previous studies using retention intervals of 24 h (see earlier discussion). In contrast, however, RIF was present after sleep. Indeed, recall of the control items, but not the unpracticed items, was reduced across a 12-h wake interval, whereas recall of both item types was largely unaffected across the 12-h sleep interval, which suggests that sleep affected RIF mainly through sleep-associated consolidation of the control items (see Fig. 6B). These results show that whether delay eliminates RIF or not can depend on whether sleep or wake follows closely upon retrieval practice. Because no control of this factor has been reported in the previous studies employing retention intervals of 24 h or 7 days, part of the variance between studies may have to do with this particular factor.

2.03.6.2 The Role of Interpolated Learning for Retrieval-Practice Effects

Quite a number of studies examined the role of length of retention interval between retrieval practice and test for the size of the RIF effect, whereas to date, only a single study examined the role of interpolated learning for the RIF effect. Arguably, the results on the role of length of retention interval for RIF may generalize to the effects of interpolated learning. Indeed, if the reason forgetting occurs over time was mostly due to interfering activities over that time, then one could expect that the effect of interpolated learning mimics the effect of increased delay. However, in most cases, delay-induced forgetting not only will be due to increased interference but also will be due to a number of factors, including changes in internal and external context between study and test (e.g., Estes, 1955; McGeoch, 1932; Mensink and Raaijmakers, 1988). If so, there is no a priori guarantee that the results for the role of length of retention interval generalize to the conditions of interpolated learning.

Abel and Bäuml (2014) examined how the interpolated learning of new information between practice and test influences the RIF effect. In two experiments that used either semantically or perceptually categorized lists, they found the learning of additional category exemplars to impair recall of the control items, which replicates the standard finding of retroactive interference. However, no such impairment arose for the recall of the unpracticed items. Consistently, in both experiments, the RIF effect was absent when interpolated learning had occurred. This result mimics that of the role of length of retention interval for RIF, indicating that both manipulations show the expected effects on the control items, but do not induce any major influence on recall of the unpracticed items. Because, in the Abel and Bäuml (2014) study, length of retention interval and interpolated learning also did not influence recall of the practiced items, the findings parallel to those of the effect of nonselective retrieval practice, indicating that retrieval practice generally insulates against the effects of time-dependent forgetting and retroactive interference, for both practiced and unpracticed items.

2.03.6.3 Summary

The results of the studies reported in this section show a critical role of retention interval between practice and test for RIF. They indicate that after longer retention intervals of 12 or 24 h, the RIF effect can be reduced or even eliminated. Similarly, they demonstrate that the interpolated learning of new information between practice and test can eliminate RIF. In all these cases, standard effects of retention interval arose for the control items, i.e., time-dependent forgetting and retroactive interference, whereas these effects were diminished or even absent for the (practiced and) unpracticed items. The findings impose important empirical restrictions on theories of RIF, challenging all current accounts of RIF.

2.03.7 When Selective Retrieval Improves Recall of Other Items

The studies reported in the previous sections strongly suggest that selective retrieval of some memories typically impairs recall of other memories. Although the experimental evidence in favor of this view is in fact overwhelming, the finding also raises a few questions. One question, for instance, is how the finding fits with (some) people's intuition that it sometimes feels as if retrieval of some episodes can initiate a chain of retrieval processes along which a seemingly forgotten memory is being reconstructed. Another question is how the finding fits with results from eyewitness memory research, which indicate that recall of some details of a previously experienced event can activate not-yet-recalled target information (see the section Introduction).

A look into the literature on RIF reveals that most studies on RIF (and output interference) share the feature that the context during selective retrieval is highly similar to the context during study (for an exception, see MacLeod and Macrae, 2001). Indeed, in many studies the selective retrieval phase followed the study phase immediately without any delay between the two experimental phases (e.g., Abel and Bäuml, 2014; Anderson et al., 1994; Jonker et al., 2013). In most of the remaining studies, there were short retention intervals of up to 5 min between the two experimental phases, mostly filled with simple counting or calculation tasks to minimize the possible contribution of short-term memory during selective retrieval (e.g., Bäuml, 2002; Hicks and Starns, 2004; Spitzer and Bäuml, 2007). Simple counting and calculation tasks are fairly neutral with respect to context and typically do not induce any major change in participants' mental states (Klein et al., 2007). Against this background, the question arises whether selective retrieval would still impair memory for other items, if access to study context was impaired during selective retrieval and the stored representation of the study context does not easily come to mind, voluntarily or involuntarily.

2.03.7.1 Evidence for Two Faces of Selective Retrieval

In a recent series of studies, Bäuml and colleagues investigated the effects of selective retrieval on nonretrieved items when access to study context during selective retrieval was impaired. Different experimental manipulations were employed to impair study context access, and the effects of selective retrieval under such conditions were compared to conditions, in which access to study context was largely maintained. For instance, Bäuml and Samenieh (2012) examined the effects of selective retrieval employing list-method directed forgetting to vary study context access. Participants were given two lists of unrelated items for study. Between study of the two lists, participants received a cue to either forget or continue remembering the items of the first list. Later, memory of predefined target items from the original list was tested using the output-order task. Testing differed in whether participants were asked to recall the target items first [which created the control (target) items] or to recall the remaining (nontarget) items prior to the target items (which created the unpracticed [target] items). As expected, when target items were recalled first, recall (of the control items) was higher in the remember condition than in the forget condition, replicating the basic directed forgetting effect (see Bjork, 1989). However, in the remember condition, recall of the targets decreased after preceding selective retrieval of the list's remaining items, thus creating lower recall of unpracticed than control items, whereas in the forget condition, target recall increased after preceding selective retrieval (see **Fig. 7A**; for a more detailed demonstration of this pattern, see Bäuml and Samenieh, 2010).

A second indication that the effects of selective retrieval can depend critically on access to study context comes from an experiment in which effects of selective retrieval were examined with and without context change after study (Bäuml and Samenieh, 2012). The study again employed the output-order task to induce practice effects and Sahakyan and Kelley's (2002) imagination task to change participants' internal states. Participants studied two item lists and, between study of the

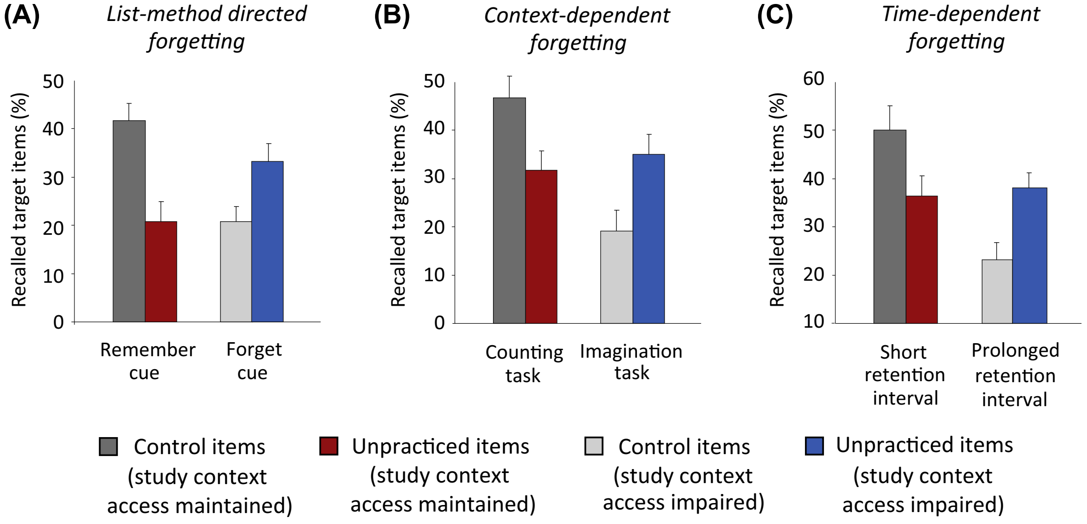

Figure 7 Effects of selective retrieval on unpracticed items when access to study context during selective retrieval is maintained versus when it is impaired. (A) Employing list-method directed forgetting to vary study context access: relative to control items, selective retrieval impaired recall of unpracticed items after a remember cue but improved recall after a forget cue. (B) Employing context-dependent forgetting to vary study context access: relative to control items, selective retrieval impaired recall of unpracticed items when a counting task followed study but improved recall when an imagination task followed study. (C) Employing time-dependent forgetting to vary study context access: relative to control items, selective retrieval impaired recall of unpracticed items after a short retention interval between study and selective retrieval but improved recall after a prolonged retention interval. Control items, predefined target items that were recalled first; unpracticed items, predefined target items that were recalled after selective retrieval of the list's remaining items. Error bars represent standard errors. Adapted from (A) Bäuml, K.-H.T., Samenieh, A., 2012. Selective memory retrieval can impair and improve retrieval of other memories. J. Exp. Psychol. Learn. Mem. Cogn. 38, 488–494; (B) Bäuml, K.-H.T., Samenieh, A., 2012. Selective memory retrieval can impair and improve retrieval of other memories. J. Exp. Psychol. Learn. Mem. Cogn. 38, 488–494; (C) Bäuml, K.-H.T., Schlichting, A., 2014. Memory retrieval as a self-propagating process. Cognition 132, 16–21.

two lists, counted backward from a three-digit number or performed a mental imagination task. The mental imagination task is assumed to create a change in participants' internal context, which leads to a contextual mismatch between participants' testing context and participants' study context during first-list learning, and thus to forgetting of the first list items (e.g., Pastötter and Bäuml, 2007; Sahakyan and Kelley, 2002). After study of the second list, participants were asked to recall predefined target items from the first list, either first or after preceding recall of the list's remaining items. As expected, when target items were recalled first, recall was higher in the counting condition than in the imagination condition, replicating basic context-dependent forgetting (see Sahakyan and Kelley, 2002). More importantly, recall of targets decreased after preceding selective retrieval of the list's remaining items in the counting condition, whereas target recall increased after preceding selective retrieval in the imagination condition (see **Fig. 7B**).

A third demonstration that the effects of selective retrieval can depend on study context access arose from work in which time-dependent forgetting was employed to manipulate study context access (Bäuml and Schlichting, 2014). Indeed, Bäuml and Samenieh's (2012) finding that changes in context between encoding and selective retrieval can induce beneficial effects of selective retrieval suggests that after prolonged retention intervals—in which often a considerable amount of external and internal contextual change arises and external and internal contextual elements of the study phase can become inaccessible over time (e.g., Estes, 1955; McGeoch, 1932; Mensink and Raaijmakers, 1988)—retrieval may also improve recall. In this study, participants learned a list of unrelated words in Experiment 1 and more integrated prose material in Experiment 2. After a short retention interval of a few minutes or a prolonged retention interval of 48 h, participants then recalled predefined target items of the study material. Employing the output-order task, the target items were recalled first or after prior selective retrieval of some of the material's other items. In both experiments, selective retrieval was found to impair recall of other studied items after the short retention interval, but to improve recall of the other items in the prolonged retention interval condition (see **Fig. 7C**).

2.03.7.2 Explaining the Two Faces of Selective Retrieval

The studies reported in the previous paragraphs show that the effects of selective memory retrieval can depend on study context access. When access to study context is largely maintained during selective retrieval, such as after a remember cue, a counting task, or a short delay filled with neutral distractor tasks, selective retrieval induces detrimental effects on other items. In contrast, when access to study context is impaired—by presentation of a forget cue, an imagination task, or a prolonged retention interval after study—selective retrieval can induce beneficial effects on other items (see Bäuml et al., 2017, for a review on the two faces of selective retrieval).

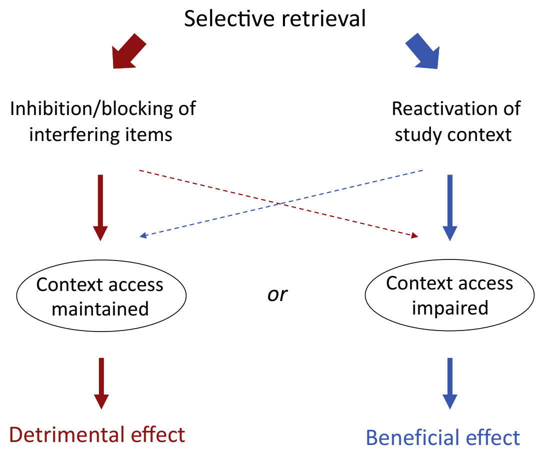

Figure 8 An account of the effects of selective retrieval on nonretrieved items. The account assumes that selective retrieval generally triggers inhibition and blocking as well as context reactivation processes. The relative contribution of the two types of processes is supposed to depend on study context access. When study context access is (largely) maintained, the relative contribution of inhibition and blocking is assumed to be larger than that of context reactivation, so that selective retrieval induces a detrimental effect on other items. In contrast, when study context access is impaired, the relative contribution of context reactivation processes is assumed to be larger than that of inhibition and blocking, so that selective retrieval creates a beneficial effect on other items.

On the basis of the two-factor account of RIF, which is supposed to explain the detrimental effect of selective retrieval (see the section Explaining the Retrieval Specificity Findings), Bäuml and Samenieh (2012) suggested a new account to explain both faces of selective retrieval (see **Fig. 8**). According to this account, selective retrieval generally triggers two types of processes: inhibition and blocking of interfering memories (e.g., Anderson, 2003; Roediger and Neely, 1982; Rupprecht and Bäuml, 2016) and reactivation of the study context (e.g., Howard and Kahana, 2002; Raaijmakers and Shiffrin, 1981). Critically, the relative contribution of the two types of processes is supposed to depend on access to study context during selective retrieval. The proposal is that the contribution of inhibition and blocking is larger than that of context reactivation when access to the study context is (largely) maintained. In such case, interference between items may be high enough so that selective retrieval triggers inhibition and blocking of the other items, whereas not much room is left for context reactivation processes. As a net result, recall of the other items may be reduced and RIF may arise. In contrast, the contribution of context reactivation processes is proposed to be larger than that of inhibition and blocking when access to the study context is impaired. In such case, interference between the single items may be reduced, so that less room is left for inhibition and blocking processes, whereas much room is left for context reactivation. Such context reactivation may reactivate the study context, which may serve as a retrieval cue for recall of the remaining items and thus improve subsequent recall.

A few more recent studies examined the account in further detail. For instance, as reported in the section Retrieval Specificity, there is evidence from numerous studies that the detrimental effect of selective retrieval is often retrieval specific, i.e., it arises after selective retrieval but not after selective restudy, at least when standard restudy trials are employed. With these findings the question arises whether retrieval specificity does also hold for the beneficial effect of selective retrieval on nonretrieved items. On the basis of the account of selective retrieval introduced above (see the section Explaining the Two Faces of Selective Retrieval) and the comprised view that the beneficial effect is driven by reactivation of the retrieved items' study context, there is reason to expect that the beneficial effect is not retrieval specific and that both selective retrieval and selective restudy can improve recall of other items. The expectation arises from context retrieval theory (e.g., Greene, 1989; Thios and D'Agostino, 1976) and more recent computational models that embody variants of the theory (Howard and Kahana, 2002; Polyn et al., 2009). Context retrieval theory assumes that when a previously studied item is repeated, be it by virtue of reexposure or its successful recall, it retrieves the context in which it was originally presented, which may then be used to cue recall of the other items. Results on the contiguity effect and the spacing effect, for instance, support such proposal (e.g., Greene, 1989; Howard and Kahana, 1999).

Bäuml and Dobler (2015) reported the results of two experiments, in which it was examined whether the two opposing effects of selective retrieval differ in retrieval specificity. Although different methods were used to impair study context access during selective retrieval, i.e., a forget cue in Experiment 1 and a prolonged 48-h retention interval in Experiment 2, and different tasks were employed for selective retrieval, i.e., the retrieval-practice task in Experiment 1 and the output-order task in Experiment 2, the results of the two experiments converged on the same main result. Indeed, when study context access was maintained, selective retrieval but not selective restudy induced forgetting of other items, supporting the view that the detrimental effect is retrieval specific. In contrast, when study context access was impaired, both selective retrieval and selective restudy improved recall of the other items, indicating that retrieval specificity does not hold for the beneficial effect of selective retrieval.

A study by Wallner and Bäuml (2016) provided fairly direct evidence that the beneficial effect of selective retrieval is driven by context reactivation processes. This study examined whether the beneficial effect of selective retrieval on nonretrieved items is reduced or even disappears, if participants' mental context is reinstated immediately before selective retrieval starts. (Partial) Reinstatement of the study context should reduce the room for further retrieval-induced context reactivation processes and, following the aforementioned account, should thus reduce or eliminate the beneficial effect of selective retrieval. Moreover, if reinstatement of the study context was complete, even detrimental effects of selective retrieval should arise. In fact, a complete reinstatement of the study context should also reinstate interference between the items and thus trigger inhibition and blocking, leading to RIF.

Wallner and Bäuml (2016) asked participants to study a list of unrelated items followed by a 10-min retention interval that included an imagination task to enhance contextual drift. At test, the output-order task was employed and participants were asked to recall the predefined target items of the list first or after preceding retrieval of the list's remaining items. They found the typical beneficial effect of selective retrieval on nonretrieved items when participants retrieved the single items without any preceding mental reinstatement of the study context. In contrast, when participants tried to mentally reinstate the study context before they retrieved the single items a detrimental effect of selective retrieval arose; while reinstating the context, they were asked to take a minute to recall their thoughts, feelings, and emotions before the beginning of the study phase and to remember the strategies they used during study of the single items (see Sahakyan and Kelley, 2002). These results provide direct evidence for the critical role of impaired study context access for the beneficial effect of selective retrieval. They thus support both the context reactivation interpretation of the effect and the account introduced earlier to explain the two faces of selective memory retrieval.

2.03.7.3 Summary

The results of the studies reported in this section show that the effects of selective retrieval can depend on study context access during selective retrieval. When access to study context is maintained, selective retrieval induces detrimental effects on other memories, whereas when study context access is impaired, it can induce beneficial effects on other memories. This evidence for two faces of selective retrieval reveals new insights into the mechanisms mediating the effects of selective retrieval, indicating that selective retrieval not only triggers inhibition or blocking, which create the detrimental effect, but also induces context reactivation processes, which create the beneficial effect.

2.03.8 Individual Differences

Memory performance is not the same in all people but can differ drastically between individuals. For instance, there is abundant evidence that individual differences in age or working memory capacity (WMC) can influence a person's long-term memory performance. Indeed, older adults as well as low-WMC individuals are often found to show reduced recollection of previously studied material and to be more prone to the negative effects of distraction on memory, when compared to younger adults or high-WMC individuals (e.g., Hasher and Zacks, 1988; Souchay et al., 2007; Unsworth and Engle, 2007). WMC, not age, has also been shown to influence the effects of nonselective retrieval practice on practiced items. Both young children and older adults were reported to show beneficial effects similar to those reported in young adults (e.g., Lipowski et al., 2014; Meyer and Logan, 2013), whereas low-WMC individuals were found to show larger effects of retrieval practice than high-WMC individuals (Agarwal et al., 2016). Effects of age and WMC were also examined in the context of selective retrieval practice, indicating that depending on age and WMC, individuals can well differ in their effects of selective retrieval. This section provides a short overview of this work.

2.03.8.1 Working Memory Capacity

2.03.8.1.1 Working Memory Capacity and the Detrimental Effect of Selective Retrieval

Results from numerous studies indicate that individuals with higher WMC are better able to deal with interference and inhibit task-irrelevant information than individuals with lower WMC (Redick et al., 2007). Consistently, measures of WMC have been found to predict performance in a number of cognitive tasks supposed to require controlled inhibition, including the Stroop task (Kane and Engle, 2003), the antisaccade task (Kane et al., 2001), and dichotic listening (Conway et al., 2001). Following the view that WMC is related to the efficiency of inhibitory control processes, at least on the basis of the inhibition account of RIF, one may thus expect that individuals with higher WMC show stronger detrimental effects of selective retrieval than individuals with lower WMC.

This expectation was tested in three studies (Aslan and Bäuml, 2011, 2012; Storm and Bui, 2017), measuring the detrimental effects of selective retrieval in younger and older adults and relating them to their performance in the operation span (OSPAN) task (Turner and Engle, 1989). The OSPAN task is a widely used tool in individual-differences research; it requires participants to simultaneously store and process information and provides reliable and valid measures of individuals' WMC (see Conway et al., 2005). In all three studies, study context access was largely maintained during selective retrieval and thus detrimental effects of selective retrieval arose, which replicates the results of typical RIF studies. More importantly, all three studies found a positive relationship between WMC and RIF, with high-WMC individuals showing more forgetting than low-WMC individuals, which indicates a critical role of WMC for the detrimental effect of selective retrieval (but see Mall and Morey, 2013).

2.03.8.1.2 Working Memory Capacity and the Beneficial Effect of Selective Retrieval

WMC can also influence the beneficial effect of selective retrieval on unpracticed items. A priori, a corresponding expectation may arise from results on context reactivation processes. These results indicate that for the beneficial effect to emerge, the reactivated context information needs to be maintained in working memory during target recall, and disruption of such maintenance may reduce the reinstated context's activation level and thus its effectiveness in cuing the target information (Dobler and Bäuml, 2012; Polyn et al., 2009). Because the concurrent maintenance of context information and recall of target information should place relatively high demands on working memory, individuals may thus differ in their capability to capitalize on retrieval-induced context reactivation and individuals with higher WMC may show a larger beneficial effect of selective retrieval than individuals with lower WMC.

Corresponding evidence arose from a study by Schlichting et al. (2015). They addressed the issue in an experiment in which they impaired participants' access to study context by changing participants' context after study. This context change induced a beneficial effect of selective retrieval on the unpracticed items at test, which replicates the results from prior work (e.g., Bäuml and Samenieh, 2012). Participants' WMC was assessed via the OSPAN task. As expected, a positive relationship between WMC and the beneficial effect of selective retrieval arose, with high-WMC individuals showing a stronger beneficial effect on nonretrieved items than low-WMC individuals. This finding suggests that individuals with higher WMC are better able to capitalize on retrieval-induced context reactivation than individuals with lower WMC, indicating that WMC may influence both the detrimental and beneficial effects of selective retrieval.

2.03.8.2 Individuals' Age

2.03.8.2.1 Age and the Detrimental Effect of Selective Retrieval

The second individual factor modulating the detrimental effect of selective retrieval is individuals' age. RIF has been widely employed in developmental research primarily to examine age-related changes in inhibitory control capabilities. Indeed, a prominent view in both cognitive development and cognitive aging is that inhibitory control capabilities vary substantially over the lifespan, being efficient and at peak in young adults but fairly inefficient in children and older adults (Bjorklund and Harnishfeger, 1990; Hasher and Zacks, 1988). Following this view and the proposal that RIF (partly) reflects the operation of inhibitory control processes, the expectation may arise that the effect may be reduced, if not eliminated, in children and older adults, relative to young adults.

Zellner and Bäuml (2005) examined this expectation in first, second, and fourth graders and in young adults, employing both the retrieval-practice and the output-order tasks and using categorized word lists as study material and category-cued recall at test. In the experiments, study and selective retrieval were separated by a short retention interval, thus largely maintaining study context access during selective retrieval. The authors found significant RIF in all four age groups, with no age differences in amount of forgetting, suggesting intact inhibition in school-aged children's selective retrieval (for similar results, see Conroy and Salmon, 2005; Ford et al., 2004; Lechuga et al., 2006).

In another study, Aslan and Bäuml (2010) examined selective retrieval effects in kindergartners, second graders, and young adults, using both category-cued recall and item recognition. They employed the retrieval-practice task with a short retention interval between study and selective retrieval. Results revealed that although all three age groups showed significant RIF in recall, only adults and second graders, but not kindergartners, showed forgetting in item recognition. Because inhibition-based RIF should be present in recall *and* recognition (see the section Retrieval Specificity), these findings indicate that in adults and second graders, but not in kindergartners, RIF is mediated by (efficient) inhibition, supporting the proposal of an inhibitory deficit in kindergartners', but not school-aged children's, selective memory retrieval.

Studies examining the detrimental effect of selective retrieval at the other end of the lifespan generally found reliable detrimental effects of selective retrieval in older adults that often was indistinguishable in size from that of young controls. In particular, the forgetting was not only found when using category-cued recall (e.g., Aslan et al., 2007, Experiment 1; Moulin et al., 2002) but was also present with item recognition (Ortega et al., 2012, Experiment 1) or independent probe tests (Aslan et al., 2007, Experiment 2), indicating that older adults' RIF is (partly) inhibition based, and this inhibition does not decline with age.

However, the studies reporting age invariance in RIF mostly examined older adults who, with regard to their age, corresponded roughly to what has been called "young-olds" in the cognitive aging literature, that is, individuals between 60 and 75 years of age. Aslan and Bäuml (2012) compared such young-old adults with a group of "old-old" adults, that is, individuals older than 75 years. They employed the retrieval-practice task with a short retention interval between study and selective retrieval, and item recognition at test. Doing so, Aslan and Bäuml replicated the finding of intact RIF in the group of young-olds but found an elimination of the effect in the group of old-olds, indicating that RIF may be a late-declining capability.

2.03.8.2.2 Age and the Beneficial Effect of Selective Retrieval

There is thus quite a number of studies that addressed the developmental trajectory of the detrimental effect of selective retrieval, but to date, only two studies examined the developmental trajectory of the beneficial effect, one with young children and the other with older adults. Aslan and Bäuml (2014) examined the presence of the beneficial effect in second, fourth, and seventh graders. Employing list-method directed forgetting to modulate study context access, the children studied a list of unrelated items and, after study, received a cue to either forget or continue remembering the list. Following study of a second list, memory of predefined target items of the original list was assessed using the output-order task, that is, either with or without preceding selective retrieval of the

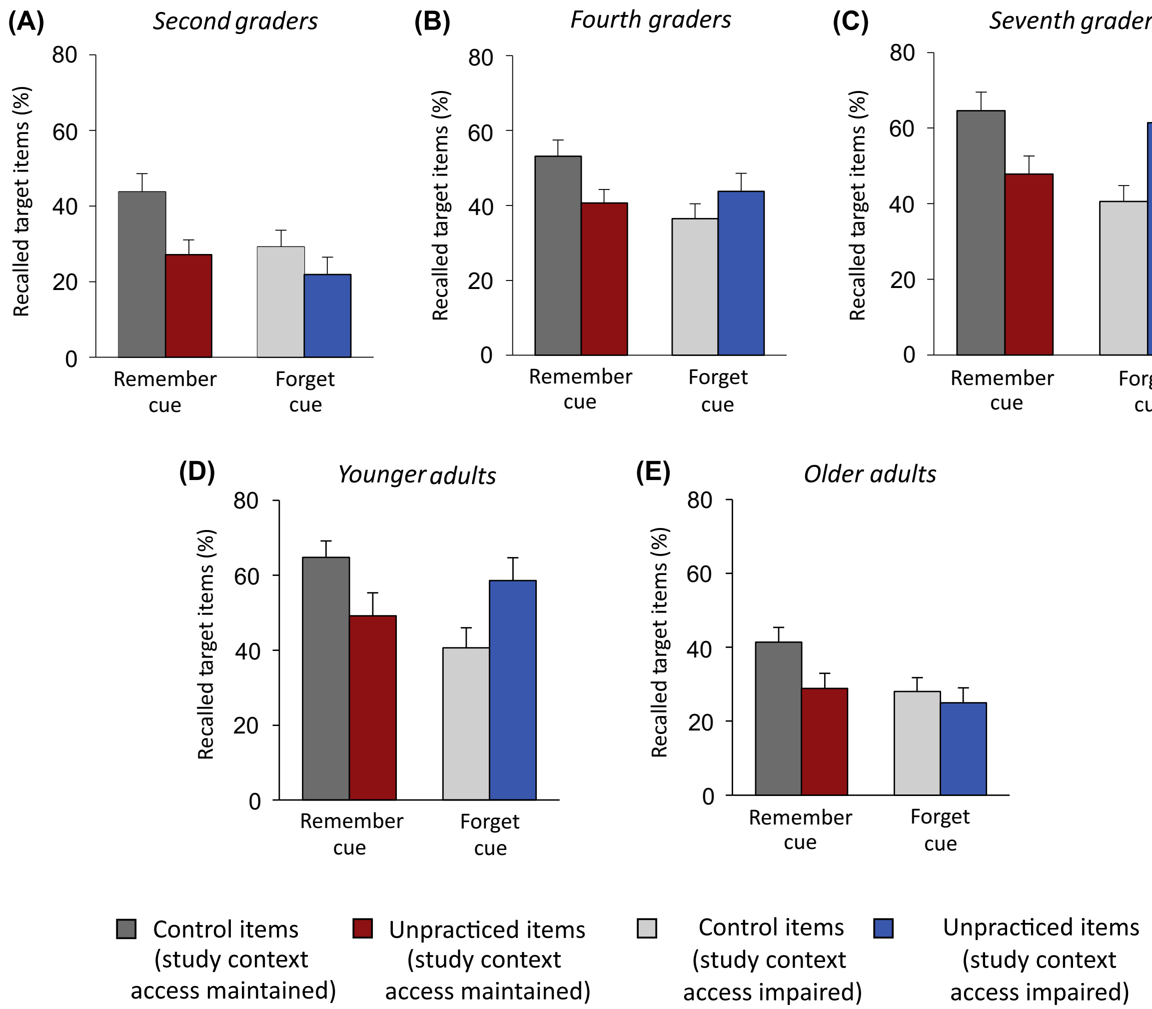

Figure 9 Effects of selective retrieval on unpracticed items in younger and older children and in younger and older adults. (A), (B), (E) Relative to control items, selective retrieval impaired recall of unpracticed items after a remember cue but left recall of unpracticed items unaffected after a forget cue. (C), (D) Relative to control items, selective retrieval impaired recall of unpracticed items after a remember cue but improved recall of unpracticed items after a forget cue. Control items, predefined target items that were recalled first; unpracticed items, predefined target items that were recalled after selective retrieval of the list's remaining items. Error bars represent standard errors. Adapted from Aslan, A., Bäuml, K.-H.T., 2014. Later maturation of the beneficial than the detrimental effect of selective memory retrieval. Psychol. Sci. 25, 1025–1030; Aslan, A., Schlichting, A., John, T., Bäuml, K.-H.T., 2015. The two faces of selective memory retrieval: earlier decline of the beneficial than the detrimental effect with older age. Psychol. Aging 30, 824–834.

list's remaining items. Preceding selective retrieval impaired recall of to-be-remembered target items, regardless of age, thus replicating the typical finding of intact RIF in school-aged children (see the section Age and the Detrimental Effect of Selective Retrieval). In contrast, preceding selective retrieval improved recall of to-be-forgotten target items in seventh graders, but not in fourth and second graders, indicating that elementary school children can or do not yet capitalize on retrieval-induced context reactivation (see Fig. 9A–C).

Addressing the beneficial effect in older adults, Aslan et al. (2015) examined in two experiments whether older adults, who typically show the detrimental effect of selective retrieval, also show the beneficial effect. Both experiments employed the output-order task. In Experiment 1, younger participants (aged 20–35 years) as well as older participants (older than 60 years) were examined, and study context access was manipulated using the listwise directed-forgetting task. Results showed a detrimental effect of selective retrieval on to-be-remembered target items regardless of individuals' age, whereas the beneficial effect of selective retrieval on to-be-forgotten target items was present in the younger adults only. In Experiment 2, a large sample of participants from a relatively wide age range (40–85 years) was examined, and study context access was manipulated by varying the retention interval between study and selective retrieval. Overall, a detrimental effect of selective retrieval arose when the retention interval was relatively short, but a beneficial effect arose when the retention interval was prolonged. In particular, the size of the beneficial effect decreased gradually with age, indicating that older adults, like younger children, have difficulty to capitalize on retrieval-induced context reactivation (see Fig. 9D and E).

2.03.8.3 Summary

The results of the studies reported in this section show that individuals' WMC can modulate the effects of selective retrieval on other items. This holds for both the detrimental and the beneficial effects, and in both cases, higher WMC is accompanied by stronger effects of selective retrieval. Results on the lifespan trajectories of the two effects of selective retrieval reveal an age-related dissociation in retrieval dynamics, indicating later maturation and earlier decline of the beneficial than the detrimental effect of selective retrieval. The detrimental effect shows up around the time of school entry, remains stable for most part of the lifespan, and becomes inefficient again not until very old age, whereas the beneficial effect of selective retrieval develops sometime between fourth and seventh grade and begins to decline at an age at which the detrimental effect is still intact (i.e., in young-old adults).

2.03.9 Conclusions

Regardless of whether retrieval is selective or nonselective, it enhances memory of the retrieved information. This enhancement effect is typically larger than the benefit that is caused when repetition of studied material occurs by virtue of restudy. Indeed, relative to restudy trials, retrieval reduces retrieved items' time-dependent forgetting and it reduces their susceptibility to retroactive interference. These beneficial effects of retrieval have been suggested to be mediated by semantic elaboration of the retrieved information or by the addition of unique contextual features to the items, although the proposal of a combination of the two processes may appear as an even more promising account of these beneficial effects.

However, retrieval can also induce forgetting, at least when retrieval is selective. Indeed, when individuals retrieve a subset of previously studied material only, retrieval often impairs memory of the nonretrieved information. Such RIF is a very general effect, which has been observed over a wide range of settings and a wide range of memory tests. It has been found to be retrieval specific, i.e., to arise typically after selective retrieval but not after selective restudy, and to depend on the nonretrieved items' interference potential during selective retrieval. The RIF effect is also quite persistent, although the forgetting seems to decrease in amount—and may sometimes even disappear—when the delay between selective retrieval and test is increased and retroactive interference is present at test. The reason is that, like retrieved items, nonretrieved contents show reduced time-dependent forgetting and reduced susceptibility to retroactive interference.

Many findings in the RIF literature are consistent with the view that RIF is mediated by inhibitory processes. This account assumes that during selective retrieval the not-to-be-retrieved items interfere and are inhibited to reduce the interference. Such inhibition is proposed to weaken the items' memory representation, so that memory of these items is impaired over a wide range of memory tests, which agrees with the empirical findings. The inhibition account is also in line with the finding that RIF is often retrieval specific and that it can depend in amount on the nonretrieved items' interference potential. However, not all findings in the literature can be explained by inhibition. In particular, there is evidence that blocking processes can also contribute to RIF and retrieval-induced context change processes may add to the effect as well. Together, the findings thus motivate the view of several mechanisms playing a role in RIF.

While the literature on RIF clearly demonstrates that selective retrieval can induce forgetting of other memories, this demonstration mostly arose when context during selective retrieval was similar to context during study. Against this background, more recent studies now indicate that when access to study context is impaired during selective retrieval, retrieval may also improve memory of the nonretrieved information. Unlike the detrimental effect of selective retrieval, this beneficial effect is not retrieval specific and generalizes to selective restudy trials. The effect has been attributed to context reactivation processes, assuming that selective retrieval not only triggers inhibition or blocking processes but also induces reactivation of the study context. The reactivated context can serve as an effective retrieval cue and thus improve memory performance.

Until at least the 1970s, retrieval was generally regarded as a self-propagating process and as being beneficial for other memories, a view dating back as far as to Aristotle (cf. Roediger, 1978) and well reflected in memory models and interrogation techniques of this time. In the subsequent decades, however, overwhelming experimental evidence arose that selective retrieval often attenuates nonretrieved memories, a finding that challenged the original view of retrieval as a self-propagating process. The recent results on the two faces of selective memory retrieval may revive the original view on retrieval quite a bit and thus contribute to a more balanced view on the effects of selective retrieval. Both memory models and interrogation techniques may benefit from such a view.

See also: 2.27 Retrieval-Based Learning: A Decade of Progress. 2.30 The Malleability of Memory.

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