Retrieval-induced remembering and forgetting

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Abstract

Retrieval changes memory and can cause powerful effects on recall performance. The effects of retrieval practice on the practiced information are typically beneficial, increasing the information's recall performance. The effects of retrieval practice on unpracticed information—if retrieval practice is selective and on some of the encoded information only—can be detrimental or beneficial. Retrieval practice typically induces forgetting of unpracticed items if selective retrieval occurs immediately after encoding. By contrast, if selective retrieval is time-lagged, retrieval practice enhances recall of unpracticed items. Retrieval practice effects are important for memory theory, providing critical insights into how retrieval shapes memories. In addition, they are of relevance for daily life—be it in educational settings, eyewitness testimony situations, or many everyday situations.

Keywords

Blocking; Context retrieval; Episodic memory; Inhibition; Retrieval; Retrieval practice; Retrieval-induced enhancement; Retrieval-induced forgetting; Selective retrieval; Testing effect

Key points

- Retrieval practice improves recall of practiced information.
- Selective retrieval practice shortly upon encoding induces forgetting of unpracticed information.
- The forgetting effect is retrieval specific and mediated by inhibition and blocking.
- Time-lagged selective retrieval practice induces recall enhancement of unpracticed information.
- The enhancement effect is not retrieval specific and mediated by context retrieval.
- Retrieval practice effects are of potential relevance for many daily life situations.

1 Introduction

A view often encountered in the public mind is that memory retrieval is nothing more than a reading out of contents from memory—and thus a process that does not affect memory itself. In contrast, a wealth of research in the past decades has demonstrated that retrieval can change memories. The so-called testing effect, for instance, illustrates this fact by showing that retrieval practice of previously encoded material typically increases the material's long-term retention and does so even more than restudy of the same information. Critically, in real life, retrieval practice often is not on all memory contents that were encoded in a specific context but instead is selective—be it in many educational settings or when an eyewitness' memory is probed—raising the question of whether such selective retrieval also influences memory of the unpracticed information. Results from recent years indeed show that selective retrieval practice influences memory for the unpracticed information and that it can both impair and improve its recallability. This chapter provides information on when selective retrieval practice typically impairs and when it improves memory for the unpracticed information. It also offers a theoretical framework to explain the two opposing effects of selective retrieval, clarifies similarities and differences between the beneficial effect of retrieval practice on the practiced information and the beneficial effect of selective retrieval on the unpracticed information, and outlines possible applications of the findings.

2 Comprehensive versus selective retrieval practice

2.1 Retrieval practice effects when retrieval practice is comprehensive

Retrieval practice changes memory and can improve memory performance of the practiced information. The testing effect provides a particularly clearcut demonstration of this important finding. For instance, in their seminal study, Roediger and Karpicke (2006) had participants study prose passages and then either repeatedly retrieve or restudy the material before the participants took a retention test after either a short 5-min or longer 2-day or 7-day delay intervals. 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. However, after the longer delays, recall was much better in the retrieval practice than the restudy condition. Moreover, the recall benefit increased with length of delay, which is consistent with the finding that retrieval practice reduces forgetting over time (Carpenter et al., 2008) and indicates the retrieval practice induces lasting effects on memory performance. The testing effect has been demonstrated over a wide range of study materials, including verbal material, pictures, or autobiographical memories. It has also been shown for different final test formats, like free recall, cued recall, and item recognition, and has been observed not only in lab-based studies but also in classroom settings (see Karpicke, 2017).

Different accounts of the testing effect provide different ideas about the cognitive mechanisms that may underlie this enhancement effect—like the bifurcation model, the elaborative retrieval account, or the episodic context account. According to the bifurcation model, retrieval practice leads to a particularly high level of strengthening of the successfully practiced material. This level exceeds that for restudied material and can reduce time-dependent forgetting in response to retrieval practice (Kornell et al., 2011). The elaborative retrieval account assumes that when individuals attempt to retrieve a previously studied item from memory, semantically related memory representations are co-activated during the search for the item, and this semantic elaboration during initial retrieval can improve recall on a later retention test (Carpenter, 2009). 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 (Karpicke et al., 2014). Each of these accounts can explain many findings on the beneficial effects of retrieval practice, but none of them seems to be able to explain the full range of results (see Karpicke, 2017). However, because the mechanisms proposed in the three accounts are not mutually exclusive, they may conjointly contribute to the wide range of beneficial effects of retrieval practice.

While the testing effect demonstrates that retrieval practice can enhance long-term retention of the practiced material, an important common characteristic of testing effect studies is that participants are asked to retrieve *all* of the initially studied items, usually shortly after encoding of the initial information. This contrasts with many everyday life situations in which, either intentionally or unintentionally, only *some* of the originally encoded episodes are practiced, either shortly after encoding or time-lagged. Such selective retrieval may take place during a conversation with a colleague about some detail of an immediately preceding business meeting or a meeting that happened several days earlier, or when a person is interrogated by a police officer about a specific event that she witnessed either just a few minutes or 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 comprehensive. However, it is less clear whether selective retrieval will also affect later memory of the unpracticed material, that is, the details not mentioned in the conversation with the colleague or the events not addressed by the police officer when interrogating the witness. Arguably, selective retrieval may not influence memory for the unpracticed material, given that this material was not subject to any repetition at all. But, as this chapter will show, results from recent years show that, in general, selective retrieval does influence recall of the other, unpracticed memories.

2.2 Retrieval practice effects when retrieval practice is selective

Two lines of research have examined the effects of selective retrieval practice. In the first line of research, the effects of selective retrieval were assessed when retrieval practice occurs shortly after the initial study phase. These studies have primarily used the retrieval practice task and the output-interference task. In the retrieval practice 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 an appropriate no-retrieval practice control condition (Anderson et al., 1994). While, relative to the control condition, later recall of the practiced items is typically improved on the final test, recall of the unpracticed items is usually impaired, which is referred to as retrieval-induced forgetting (RIF). The effects of selective retrieval 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 (Smith, 1971). The typical finding was that recall success declined with the items' testing position, which indicates that recall of early-tested items impaired recall of later-tested items and thus is consistent with the finding of RIF in the retrieval practice task (for details, see Section 3).

In the second line of research, the effects of selective retrieval were assessed when selective retrieval is time-lagged, that is, when a prolonged temporal lag is applied between the initial study phase and the selective retrieval phase. Some of these studies have used a time-lagged variant of the retrieval practice task. The time-lagged retrieval practice task is similar to the classical retrieval practice task with the main difference that in the classical task, there is no (or, at most, a very short) lag between study and selective retrieval, whereas in the time-lagged version, there are lags between 20 min and a few days between phases. Doing so, time-lagged selective retrieval has been found to not only enhance later recall of the practiced material, but to also enhance later recall of the unpracticed material, which is referred to as retrieval-induced enhancement (RIE). Other studies have used the time-lagged output-order task, a variant of the classical output-interference task. In this task, participants often study a list of items before, in the final test phase, they are asked to recall a predefined half of the items (the target items) first or after selective retrieval of the list's other items. Temporal lags between 10 min and a few days between phases have been employed in these studies. The typical finding has been that recall of the target items is enhanced if the list's other items were previously retrieved, which demonstrates RIE. Together, the findings indicate that selective retrieval practice exerts effects on unpracticed memories both when retrieval practice occurs shortly after study and when it is time-lagged—though, depending on lag, results often show opposing effects on unpracticed items (for details, see Section 4).

This chapter reviews results from both lines of research on the effects of selective retrieval practice. In the first step, the chapter provides an overview of research in which retrieval practice was applied shortly after study—typically inducing RIF (Section 3)—and, in the second step, of research in which retrieval practice was time-lagged—typically inducing RIE (Section 4). Both sections cover the employed experimental tasks, typical findings, and suggested mechanisms to explain the effects, as well as the issues of retrieval specificity and persistence over prolonged retention interval. Each section ends by reviewing boundary conditions of the effects and providing a summary of the findings. Section 5 will provide a theoretical perspective to integrate the findings from the two lines of work, discuss similarities and differences between the beneficial effects of selective and comprehensive retrieval practice, mention other demonstrations of beneficial effects of selective retrieval, and outline possible applications arising from this work. Finally, the chapter will end with some conclusions on the effects of retrieval practice (Section 6).

3 Selective retrieval practice

3.1 Experimental tasks

The memory literature provides numerous demonstrations that selective retrieval practice, when conducted shortly after study, can induce forgetting of other, unpracticed material. In the 1960s and 1970s effects of selective retrieval on recall of other items were first examined employing the output-interference task, in which participants typically studied items from different semantic categories (e.g., FRUIT-*orange*, FURNITURE-*chair*, FRUIT-*banana*, FURNITURE-*table*) before, on a later test, they were provided with the category labels, one by one, and asked to produce as many of the initially studied exemplars as possible (Smith, 1971). Results often showed that recall decreases with the position of a given category in the recall sequence, indicating that items recalled at early test positions impaired recall of items at later test positions. RIF as observed in the output-interference task has been found not only with final recall tests but also when a final recognition test was applied (Criss et al., 2011). Furthermore, using the output-order variant of the task, RIF has also been found with lists of unrelated items. In this variant, participants studied unrelated items, before, in the final test phase, they were provided with the items' unique initial letters as retrieval cues and were asked to recall a predefined half of the items first or after selective retrieval of the list's other items. Recall for the predefined half of items was reduced if the other items were previously retrieved (Bäuml and Samenieh, 2010).

However, 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. For instance, participants may again study items from different semantic categories (e.g., FRUIT-*orange*, FURNITURE-*chair*, WEATHER-*storm*, FRUIT-*banana*, FURNITURE-*table*, WEATHER-*rain*) before, in a subsequent retrieval practice phase, they are asked to repeatedly retrieve a subset of the items from a subset of the categories (e.g., FRUIT-*or*___, FURNITURE-*ch*___; *retrieval practice condition*). Typically, the temporal lag between study and retrieval practice is on the order of 0–5 min. After a short delay, participants are then asked to recall all initially studied items (see Fig. 1A). As expected, recall of the

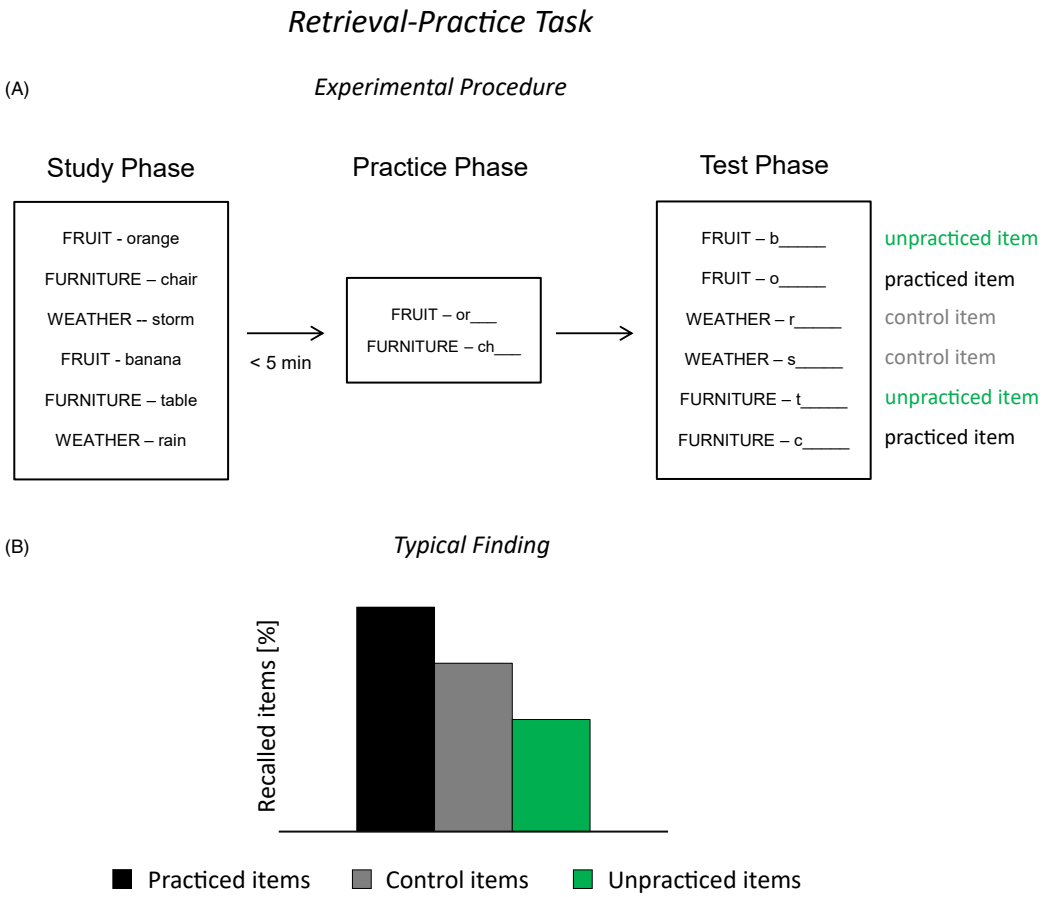

Fig. 1 (A) The retrieval practice task as applied to semantically categorized lists. In the study phase, participants study several items from different semantic categories. In the practice phase—which typically occurs no more than 5 min after the end of the study phase—participants are asked to recall a subset of the exemplars from a subset of the categories (e.g., orange, chair), providing the words' category name and unique initial letters as retrieval cues. In the subsequent test phase, participants are asked to recall all initially studied items. (B) Typical finding: Practiced items show higher recall rates and unpracticed items show lower recall rates relative to control items belonging to categories for which no retrieval practice took place.

practiced items (e.g., *orange*) is often improved on the final test, relative to recall of the control items (e.g., *storm*). 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. 1B). RIF as it is observed in the retrieval practice task is a very general phenomenon. It has been found with a variety of study materials, like visuospatial materials, text passages, or autobiographical material, and for a variety of test formats, including recall and item recognition tests (for reviews, see Bäuml and Kliegl, 2017; Storm et al., 2015). The findings from the output-interference and retrieval practice tasks thus converge on the view that selective retrieval practice can impair memory for unpracticed material.

3.2 Mechanisms

The two most prominent accounts of RIF 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 assumes that when a subset of the studied items are 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 items and impaired recall on a later memory test. The inhibition account can also explain RIF as it arises in the output-interference and output-order tasks, assuming that during test, the yet-to-be-recalled tested-last items interfere during preceding selective retrieval of the tested-first items 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, 1973; Rundus, 1973). The account can explain RIF in this task by assuming that preceding recall of tested-first items at test strengthens these items, and thus blocks recall of the remaining tested-last items due to increased interference from the early recalled items. Blocking can also account for RIF as it arises in the retrieval practice task (Raaijmakers and Jakab, 2012). Here the critical assumption is that retrieval

practice strengthens the associations between the practiced items and their category cues (e.g., *orange*), and such strengthening leads to blocking of the (not strengthened) unpracticed items at test (e.g., *banana*), thus creating RIF (for another noninhibitory account, see Jonker et al., 2013).

The finding that RIF arises across a wide variety of testing formats, such as free-recall tests, cued-recall tests, and item recognition tests, is consistent with the inhibition account of RIF. Indeed, according to this account, suppression should directly affect the representation of the unpracticed items themselves, with all retrieval routes to the inhibited item becoming less effective. In contrast, the findings challenge the blocking account, which predicts RIF to be largely absent with item recognition tests. The presentation of the "old" items from the study phase during item recognition should directly cue the episodic representations of those items without activating the shared categories, thus bypassing any form of blocking from the practiced items (see Rupprecht and Bäuml, 2016).

Findings from studies examining whether RIF also arises in independent-probe and implicit tests provide further support that inhibitory processes play a critical role for RIF. With the independent-probe procedure (Anderson and Spellman, 1995), 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 co-activate the category's practiced items (e.g., *orange*) and thus should eliminate possible blocking effects from the practiced items at test. Over the years, quite a number of studies examined cue independence of RIF. Overall, the results of such studies provided evidence in support of the proposed property (see Bäuml and Kliegl, 2017; Storm et al., 2015). They consistently reported that memory of unpracticed items was worse than memory of control items when novel retrieval cues were employed at test, which was seen as specific support for the inhibition account of RIF. Indeed, 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.

RIF was also assessed with implicit memory tests, that is, tests that do not require participants to deliberately or consciously recollect previously studied material. Examining whether RIF arises in implicit tests is 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 account of RIF. Veling and van Knippenberg (2004) addressed the issue by having participants study a categorized list of words (e.g., FRUIT-*banana*, FRUIT-*orange*, PROFESSION-*teacher*) and perform retrieval practice on a subset of the items (e.g., FRUIT-*or*___). Then, at test, participants were presented with letter strings and were asked to indicate 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 for the control items. Consistent with this expectation, the word/nonword judgments were indeed found to be slower for unpracticed items than for control items, thus demonstrating RIF. Although some further implicit tests were also shown to impair recall of unpracticed items, such as category generation and category matching, there is also evidence that not all forms of implicit tests may induce RIF (see Bäuml and Kliegl, 2017).

3.3 Retrieval specificity

The effects of comprehensive retrieval practice on the practiced items are typically larger than the effects of comprehensive restudy. This has been demonstrated numerous times with the testing effect, though mainly for longer retention intervals (see Section 2). 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. In contrast, 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.

Two methods have been employed to examine retrieval specificity of RIF: noncompetitive retrieval practice and restudy. In both methods, the to-be-practiced items were reexposed intact with the goal of strengthening the items' associations to their cue without inducing interference and inhibition of unpracticed items. 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*). 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. The results of numerous studies showed forgetting of unpracticed items after standard (competitive) retrieval practice, but no forgetting after noncompetitive retrieval practice (Anderson et al., 2000a; Hanslmayr et al., 2010, see Fig. 2A) and no forgetting after restudy cycles (Bäuml and Aslan, 2004; Ciranni and Shimamura, 1999, see Fig. 2B), which is consistent with retrieval specificity. This pattern of results supports the inhibition account but challenges the blocking account of RIF.

Arguably, the findings do not necessarily contradict the blocking account of RIF because plain reexposure 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 (Raaijmakers and Jakab, 2012). Consequently, RIF may no longer be found to be retrieval specific if retrieval was

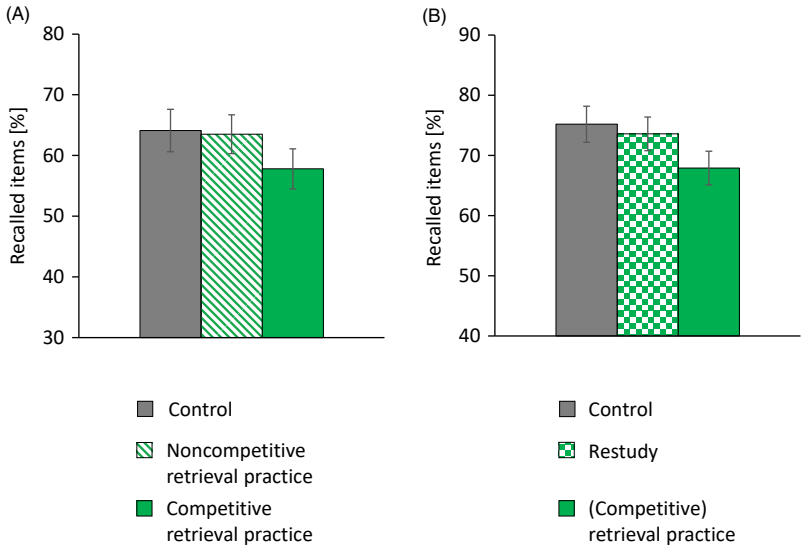

Fig. 2 Effects of competitive retrieval practice, noncompetitive retrieval practice, and restudy on recall of unpracticed items. (A) Competitive retrieval practice, but not noncompetitive retrieval practice, impaired recall of unpracticed items. (B) (Competitive) retrieval practice, but not restudy, impaired recall of unpracticed items. *Error bars* represent standard errors. Panel (A): Adapted from Hanslmayr S, Staudigl T, Aslan A, Bäuml K-HT (2010). Theta oscillations predict the detrimental effects of memory retrieval. Cognitive, Affective, and Behavioral Neuroscience 10: 329–338; Panel (B): Adapted from Bäuml K-H, Aslan A (2004). Part-list cuing as instructed retrieval inhibition. Memory and Cognition 32(4): 610–617.

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. To examine this possibility, some studies employed a potentially more demanding version of the noncompetitive retrieval practice method intended to strengthen cue–item associations (Raaijmakers and Jakab, 2012; Rupprecht and Bäuml, 2016). They presented items of relatively low frequency within their categories as study material (e.g., ROUND-*ball*) and did no longer provide the word stems of the category labels as retrieval cues during practice (___-*ball*). Doing so, the results showed that both competitive and noncompetitive selective retrieval reduced recall of unpracticed items (Raaijmakers and Jakab, 2012; Rupprecht and Bäuml, 2016), but selective retrieval only reduced recognition of unpracticed items (Rupprecht and Bäuml, 2016). Thus, also with more demanding noncompetitive retrieval practice, RIF can be retrieval specific, though not with all test formats.

As is obvious from the two preceding paragraphs, neither the inhibition account nor the blocking account can explain the whole range of findings on retrieval specificity. Therefore, Rupprecht and Bäuml (2016) suggested a two-factor account to explain the results, which assumes that 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, whereas inhibition is supposed to induce a retrieval-specific reduction in the unpracticed items' memory representation, observable over a wide range of memory tests, blocking is assumed 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. This account is consistent with the retrieval specificity findings reported above. It agrees with the observed presence of RIF in both recall and item recognition and the presence of RIF-like forgetting after certain forms of noncompetitive retrieval practice in recall but not in item recognition. In fact, because noncompetitive retrieval should induce blocking but not inhibition, it may create RIF-like forgetting in recall but not in item recognition (see also Schilling et al., 2014).

3.4 Persistence of RIF

Expectations on the role of length of delay between practice and test for the RIF effect are somewhat unclear. Whereas 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 longer delay, others have argued that inhibition may have persisting consequences (see Bäuml and Kliegl, 2017; Storm et al., 2015). Clearcut expectations are also difficult on the basis of the blocking account, although again there may be reason to expect some dissipation of the RIF effect with delay. While most RIF studies in the literature used delay intervals between practice and test of 5 min or less, some studies used longer delay intervals of 20 min, 24 h, or even several days between practice and test. The studies that used delay intervals of 20 min (Anderson et al., 1994; Anderson and Spellman, 1995) reported effect sizes of RIF quite similar to those reported in the studies with shorter delay 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 delay intervals of 24 h

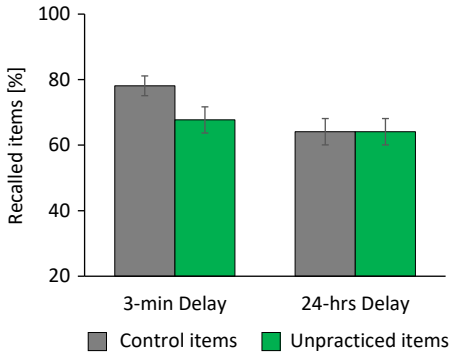

Fig. 3 Effect of delay between retrieval practice and test on recall of unpracticed items. Retrieval practice impaired recall of unpracticed items after a 3-min delay, but not after a 24-h delay. *Error bars* represent standard errors. Adapted from Abel M, Bäuml K-HT (2014) The roles of delay and retroactive interference in retrieval-induced forgetting. Memory and Cognition 42: 141–150.

between practice and test compared RIF after such prolonged delay interval with RIF after a short baseline interval of few minutes. Many of these studies reported intact RIF after the short delay but no RIF after the long delay (Abel and Bäuml, 2014; MacLeod and Macrae, 2001; see Fig. 3 and Bäuml and Kliegl, 2017).

The findings by Abel and Bäuml (2014) and MacLeod and Macrae (2001) seem to suggest that unpracticed and control items differ in forgetting over time, with control items showing typical time-dependent forgetting but unpracticed items showing somewhat reduced forgetting over time. However, caution is warranted with such a suggestion. While the suggestion may seem to be supported if forgetting over time was measured by the decrease in the absolute number of items retrieved per unit time, it may no longer be supported if the forgetting was measured in relative terms. Indeed, Wixted (2022) recently pointed out that, while time-dependent forgetting of previously studied material generally does not seem much affected by degree of learning—for instance, implemented by different numbers of study trials—when forgetting is measured in absolute terms, forgetting often has been found to be reduced for material with a higher degree of learning when forgetting is measured in relative terms. For instance, if recall drops from eight items recalled to six items recalled within a 24-h time interval for information with a high degree of learning and drops from four items recalled to two items recalled within the same time interval for information with a lower degree of learning, then the reduction in recall would be the same (i.e., two items forgotten) for the two degrees of learning when forgetting is measured in absolute terms. When measured in relative terms, however, the information with the higher degree of learning shows less pronounced forgetting with delay (i.e., 25%) than the information with the lower degree (i.e., 50%). Applied to RIF, the apparently more pronounced time-dependent forgetting of control items than unpracticed items when forgetting is measured in absolute terms does not necessarily generalize if forgetting is measured in relative terms, and thus is not necessarily inconsistent with the view that the two types of items show similar forgetting rates. Future research is required to evaluate this possibility, also because relative measures of forgetting are theoretically more relevant than absolute measures (see Wixted, 2022).

3.5 Boundary conditions of RIF

While RIF has been observed in a variety of experimental setups, there are conditions under which RIF typically does not arise. These boundary conditions of RIF are not only empirically relevant but do also impose restrictions on theories of RIF. One line of studies investigated boundary conditions of RIF by manipulating how participants are instructed to encode the study material. For instance, Anderson et al. (2000b) found that RIF was absent if 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 the inhibition account, suggesting that when practiced and unpracticed items are episodically integrated and interference between the two item types is thereby reduced, RIF can be abolished. Another study employing more complex study material provides further support for the view that relational processing can protect from RIF. Specifically, Chan (2009) had participants study text passages and manipulated the level of integration invoked during encoding by presenting the passages in either a random order (low level of integration) or coherent order (high level of integration). During subsequent retrieval practice, participants answered questions on the passage before they engaged in a final retention test in which some of the questions were repeated from retrieval practice, and some were completely new and thus unpracticed. Relative to control questions, final test recall was found to be impaired for unpracticed questions for the low integration level, thus reflecting RIF, but not for the high integration level.

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. Additional evidence for the view that item-specific processing can reduce RIF comes from research manipulating retrieval practice itself, and in particular, whether retrieval practice is performed in neutral or negative mood. Relative to neutral mood, negative mood has been argued to influence memory performance by encouraging item-specific processing, which again may reduce, if not eliminate, RIF. Bäuml and Kuhbandner (2007) induced neutral or negative moods in participants immediately prior to the retrieval practice phase by showing participants neutrally or negatively valenced pictures. While typical enhancement effects of selective retrieval practice were observed for practiced items regardless of mood, forgetting of unpracticed items arose in the neutral-mood condition but not in the negative-mood condition. The findings again suggest that item-specific processing may eliminate RIF.

Further research, which also manipulated the retrieval practice phase, has shown that distraction during retrieval practice can eliminate RIF, a finding that may have implications for the nature of the inhibitory mechanism supposedly contributing to RIF. Román et al. (2009) stressed participants' attentional resources during the retrieval practice phase using a secondary, concurrent task and found that, relative to a standard retrieval practice condition, there was no RIF effect when the secondary task was performed during retrieval practice, although recall of practiced items was still reliably enhanced. These findings were argued to support the view that RIF underlies the action of a general executive process that is engaged to control overt behavior or to inhibit irrelevant stimuli. In particular, overloading attentional resources with a secondary task should impede the action of the inhibitory mechanism and thus reduce RIF, which is exactly what Román et al. (2009) found. The pattern of results is, however, difficult to reconcile with the blocking account since the account would predict that the successful strengthening of the practiced items in the secondary-task condition should have induced impaired memory of the unpracticed items.

3.6 Summary of the findings

Retrieval can induce forgetting, at least when retrieval is selective and when it occurs shortly after encoding of the study material. RIF is a very general effect, which has been observed over a wide range of settings and memory tests. The effect has been found to be typically retrieval specific, that is, to arise in response to selective retrieval but not in response to selective restudy, and to decrease when the delay between selective retrieval and test is increased. Many findings in the RIF literature are consistent with the view that RIF is mediated by inhibitory processes, which assumes that the not-to-be-practiced items interfere during selective retrieval and are inhibited to reduce the interference. The proposal is consistent with the finding that RIF can be observed over a wide range of memory tests and is also in line with retrieval specificity of the effect. However, not all findings in the literature can be explained by inhibition and there is evidence that blocking processes can also contribute to RIF. Together, the findings thus motivate the view of several mechanisms playing a role in RIF.

4 Time-lagged selective retrieval practice

4.1 Experimental tasks

In the past 10 years, a number of studies have provided evidence that selective retrieval practice may no longer impair memory for unpracticed items when retrieval practice is time-lagged and does not occur shortly upon study. Indeed, when retrieval practice occurred at least 10 or 20 min after study, recall of the unpracticed items was found to be enhanced, rather than impaired. Corresponding evidence arose both with the output-order task and the retrieval practice task. With the output-order task, participants typically studied a list of unrelated items before, in the final test phase, they were provided with the items' unique initial letters as retrieval cues and were asked to recall a predefined subset of the items—the target items—first or after selective retrieval of the list's other items (Bäuml and Schlichting, 2014; Wallner and Bäuml, 2017). Across experiments, lag intervals between study and retrieval varied between 10 min and 48 h. In the studies that employed lag intervals between 10 and 30 min, the lag intervals were filled with distractor tasks that were unrelated to the memory task; to enhance the forgetting during the lag interval, the interval also included daydreaming tasks ("What would you do if you were invisible?"), which are known to increase forgetting (Delaney et al., 2010). In the studies that employed lag intervals of 1 or 2 days, participants were dismissed immediately after study and joined the next meeting for retrieval 24 or 48 h later; no additional distractor tasks were included. The typical finding in these studies was RIE, that is, recall of the predefined target items was enhanced if the other items were previously retrieved. The same finding emerged when prose passages were employed as study material, both when shorter passages (about 300 words) and when longer passages (about 1800 words) were used, for both a lag interval of 30 min and a lag interval of 48 h between study and retrieval.

More recently, RIE has also been examined with the retrieval practice task (Bäuml and Trißl, 2022; Kriechbaum and Bäuml, 2023, see Fig. 4). In these studies, participants mostly studied lists of unrelated items. Subsequently, an intermediate phase followed in which half of the participants engaged in retrieval practice and repeatedly retrieved a subset of the previously studied items, whereas the other half of the participants took part in an unrelated distractor task for the same duration of time. Across experiments, lag intervals between study and the intermediate phase varied between 20 min and 7 days. Lag intervals up to 30 min were again filled with distractor tasks that were unrelated to the memory task, though in contrast to the output-order task, no daydreaming tasks were included that would enhance the forgetting during the lag intervals. With lag intervals of 1.5 h and longer, participants were

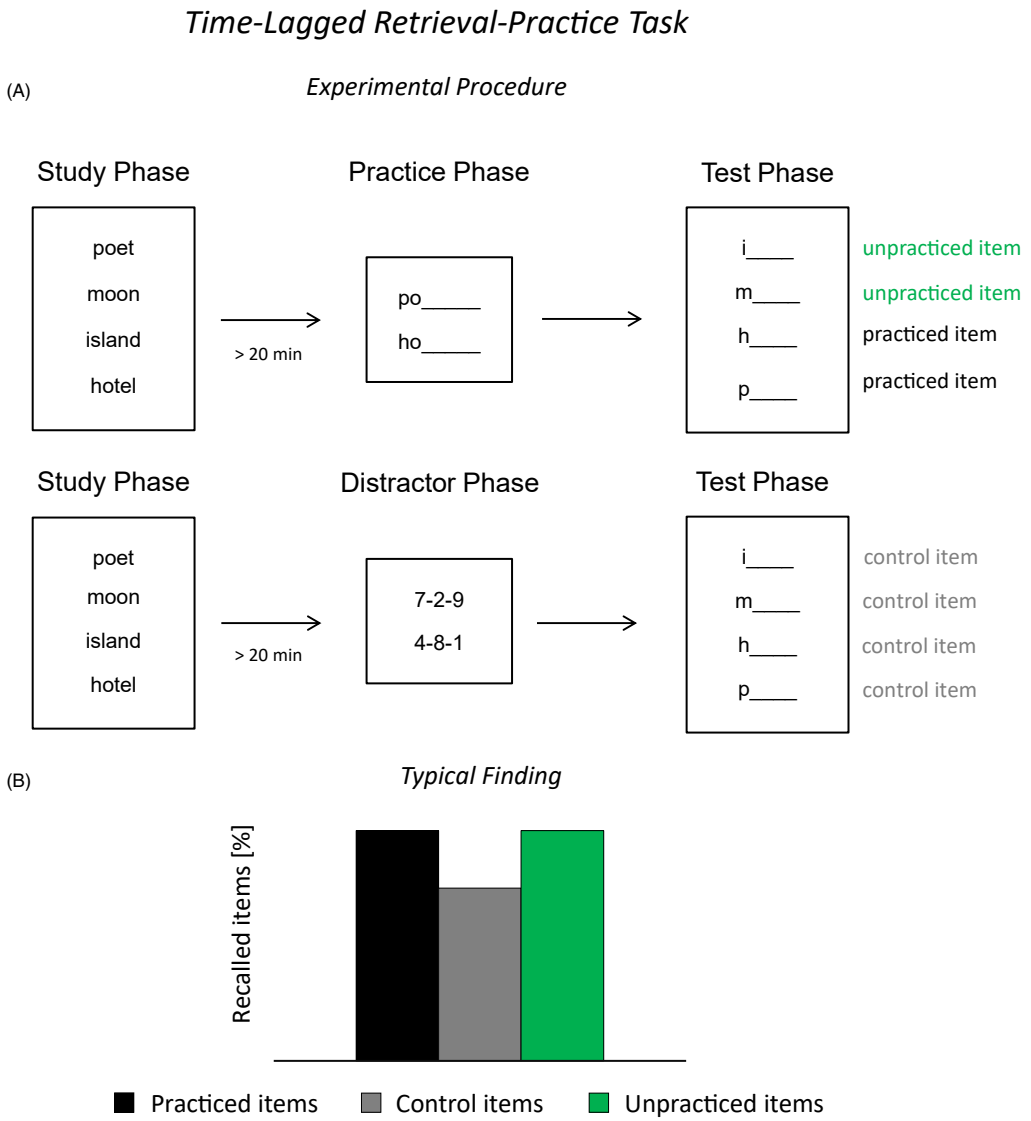

Fig. 4 (A) The time-lagged retrieval practice task as applied to lists of unrelated items. In the study phase, two groups of participants study several unrelated items. Following a temporal lag of at least 20 min, one group of participants engages in a practice phase in which they are asked to recall a subset of the items (e.g., poet, hotel), providing the words' unique initial letters as retrieval cues; another group engages in a distractor phase of equal duration in which they are asked to complete unrelated distractor activities, like triplets ordering. In the subsequent test phase, both participant groups are asked to recall all initially studied items. (B) Typical finding: Both practiced and unpracticed items show higher recall rates than control items.

dismissed after study and joined the next meeting hours or days later. Shortly after the intermediate phase, a recall test on all previously studied items was conducted for all participants. As expected, retrieval practice improved recall of the practiced items, relative to recall of the items in the control condition. More important, retrieval practice enhanced recall of the unpracticed items as well, thus showing RIE. At least for lag intervals of less than one day, the enhancement effect for the unpracticed items was even similar in size to the recall improvement for the practiced items. The finding of RIE generalized to categorized item lists when the practiced and unpracticed items belonged to different categories (Bäuml and Wallner, 2020), and did also generalize to prose material (Bäuml and Trißl, 2022).

The findings from the output-order and retrieval practice tasks converge on the view that lagged selective retrieval practice can improve memory for unpracticed material. This holds while there is a tendency between studies that the beneficial effects of retrieval practice on the unpracticed items are somewhat larger with the retrieval practice than the output-order task. Among other factors, this may be due to the fact that, with the retrieval practice task, there were typically two retrieval practice cycles, whereas, with the output-order task, there was mostly a single practice cycle in the previous studies. Interestingly, when employing the retrieval practice task and lag intervals of less than one day, retrieval practice largely eliminated the forgetting over time that had accumulated since study and thus revealed recall levels for the unpracticed items that were similar to recall levels shortly after study. For lag intervals of one day and longer, the recall enhancement was still present but the effect did no longer eliminate the accumulated

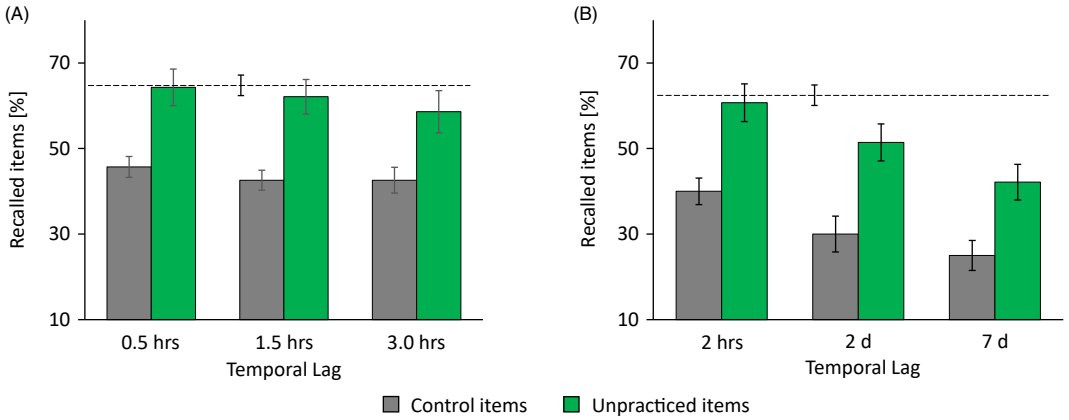

Fig. 5 Effect of temporal lag between study and retrieval practice on recall of unpracticed items. Both for temporal lags between 0.5 and 3.0 h (A) and for temporal lags between 2 h and 7 days (B), recall of unpracticed items was superior to recall of control items. The *dashed lines* represent recall of control items when these items were tested immediately after study. *Error bars* represent standard errors. Panel (A): Adapted from Bäuml K-HT and Trißl L (2022) Selective memory retrieval can revive forgotten memories. Proceedings of the National Academy of Sciences of the United States of America 119(8): e2114377119; Panel (B): Adapted from Kriechbaum VM and Bäuml K-HT (2023) The critical importance of timing of retrieval practice for the fate of nonretrieved memories. Scientific Reports 13(1): 6128.

forgetting (see Fig. 5). Lag interval thus seems to be critical for the amount of compensation against time-dependent forgetting that is entailed by selective retrieval practice.

4.2 Mechanisms

RIE has typically been explained by context retrieval (see Bäuml, 2019). It is a general assumption in computational models of memory that, when participants study items, each studied item is associated with the temporal context in which it is shown (Howard and Kahana, 2002; Raaijmakers and Shiffrin, 1981). Temporal context refers to the current pattern of activity in an individual's mind that, among others, can be influenced by environmental factors—like the external surroundings during the task—as well as internal factors—like the participant's current stress level or her expectations on the forthcoming task. Temporal context is assumed to change gradually over time so that the contextual overlap between study and retrieval will be increasingly reduced as more and more time passes between study and retrieval. The resulting reduced contextual overlap then impairs recall performance (Bower, 1972; Estes, 1955). However, context during recall is not a static entity but changes in response to recall attempts. Indeed, recall of an item can result in a partial reactivation of the context that was present when that item was studied, and this retrieved context then serves as a retrieval cue for other items with a similar context at study, facilitating recall of these items (Howard and Kahana, 2002; Polyn and Kahana, 2008). The concept of context retrieval has proven successful in explaining a number of recall findings and also provides an interpretation of Tulving (2002) proposal of mental time travel (see Polyn and Kahana, 2008).

The prior RIF work typically employed experimental settings that used short lags of no more than 5 min between study and selective retrieval and thus minimized the contextual change between study and selective retrieval (see Section 3.1). The possible effects of context retrieval therefore should have been small in these studies and be masked by inhibition and blocking. In contrast, the studies on RIE employed longer lag intervals, like 30 min or even several days, and thus induced larger reductions in contextual overlap. Such reduction in overlap should increase the role of context retrieval for the effects of selective retrieval, which may then attenuate the typical detrimental effect, eliminate it, or even reverse it into a beneficial effect. The RIE effects described above are consistent with this view and thus support a context retrieval account of the observed beneficial effects of selective memory retrieval.

Employing the retrieval practice task and lag intervals between study and selective retrieval between 30 min and 3 h, Bäuml and Trißl (2022) showed that selective retrieval can eliminate the forgetting over time that had accumulated since study, indicating that retrieval practice can effectively protect the unpracticed items from showing forgetting over time. Also employing the retrieval practice task, Kriechbaum and Bäuml (2023) extended these results by showing that context retrieval still contributes to recall when retrieval practice takes place 2 or 7 days after study, again enhancing recall of the unpracticed items. However, with these longer lag intervals, only part of the accumulated forgetting was eliminated, indicating that study context reactivation can become incomplete after very long lag. This observed role of lag interval for the effect of selective retrieval fits with the context retrieval proposal, which includes the possibility that reactivation of study context can become hard when the temporal lag between study and retrieval gets rather long and the contextual overlap between study and retrieval much reduced. Indeed, recall success during retrieval practice can be reduced after lags of several days, which may attenuate possible effects of context retrieval and thus impair chances to completely compensate against the forgetting that has accumulated since study.

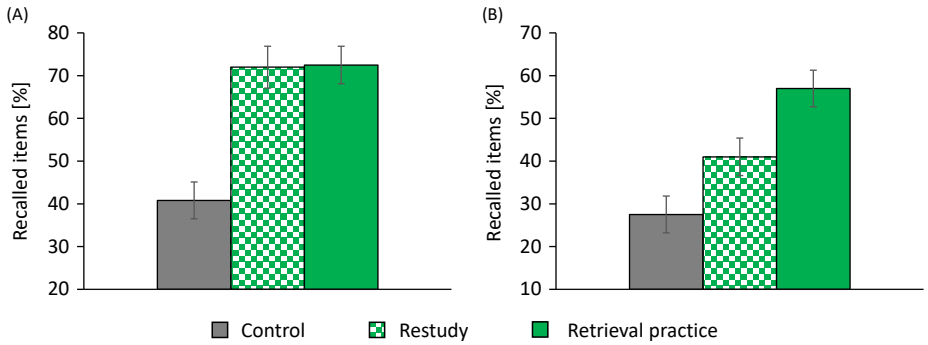

Fig. 6 Effects of retrieval practice and restudy on recall of unpracticed items. (A) Following a temporal lag of 10 min between study and retrieval practice, both retrieval practice and restudy enhanced recall of unpracticed items, and did so to a similar degree. (B) Following a temporal lag of 30 min, both retrieval practice and restudy enhanced recall of unpracticed items, though retrieval practice enhanced recall more than restudy. *Error bars* represent standard errors. Adapted from Wallner L, Bäuml K-HT (2017) Beneficial effects of selective item repetition on the recall of other items. Journal of Memory and Language 95, 159–172.

4.3 Retrieval specificity

As reported in Section 3.3, results from numerous studies have shown that RIF typically is retrieval specific. The forgetting of the unpracticed items therefore may require preceding selective retrieval of the practiced items, whereas preceding selective restudy may not be sufficient to induce the effect. Two studies addressed the issue of retrieval specificity for the beneficial effect of selective retrieval. Critically, the two studies did not expect retrieval specificity to generalize from RIF to RIE. The reason is that context retrieval, which has been suggested to mediate RIE (see Section 4.2), has often been assumed to be not restricted to retrieval but to also arise after restudy trials (Greene, 1989; Lohnas et al., 2011), a proposal also included in computational models of human memory (Howard and Kahana, 2002; Polyn et al., 2009).

Bäuml and Dobler (2015) addressed the issue using the output-order task. They compared the effects of selective retrieval and selective restudy after a longer 48-h lag between study and practice. Lists of unrelated items served as study material. Beneficial effects on the unpracticed items emerged after both practice formats, supporting the expectation that the beneficial effect of selective retrieval is not retrieval specific. The size of the beneficial effect, however, was larger after retrieval than restudy. Wallner and Bäuml (2017) also compared the effects of selective retrieval and selective restudy, again using the output-order task and again using lists of unrelated items. This time shorter lag intervals of 10 and 30 min between study and practice were employed. For both lag intervals, beneficial effects of retrieval and restudy arose (see Fig. 6), suggesting that RIE is not retrieval specific. After the 30-min lag interval, the beneficial effect was larger in response to retrieval than restudy, which generalizes the Bäuml and Dobler (2015) finding to shorter lag interval.

Wallner and Bäuml (2017) also examined the influence of the difficulty of selective retrieval on the size of the beneficial effect. After study of a list of unrelated items (Experiment 3) or coherent prose material (Experiment 4) and a subsequent lag of 30 min between study and retrieval, participants selectively retrieved some studied items after being given strong word-stem cues (app___ for apple; easy retrieval) or selectively retrieved some studied items after being given weak initial-letter cues (a___ for apple; difficult retrieval). Results showed beneficial effects after both practice formats. The size of the effects, however, varied with practice format and was larger after difficult than after easy selective retrieval. This pattern of results mimics research on desirable difficulties in learning, which has shown that variables that pose challenges for learners and make initial learning feel more difficult can provide a beneficial effect on long-term retention (Bjork, 1994). Likewise, variables that pose challenges during lagged retrieval of some memory contents may be beneficial for the recall of related memory contents.

Both the findings on retrieval specificity and the findings on the role of retrieval difficulty for the size of the beneficial effect are consistent with context retrieval. Indeed, the degree of context reactivation induced by context retrieval may be higher after retrieval than restudy. Whereas context retrieval may not be obligatory during restudy cycles, with retrieval, people deliberately search memory information about the prior occurrence of studied information. Similarly, degree of context reactivation may also be higher after difficult than easy retrieval, because difficult retrieval should force people more than easy retrieval to deliberately search memory contents. Thus, both the findings on retrieval specificity and the findings on retrieval difficulty may reflect differences in degree of induced context retrieval (for related arguments with regard to the testing effect, see Karpicke et al., 2014).

4.4 Persistency of RIE

Does RIE represent a transient or a more lasting effect? The expectations on the role of delay between selective retrieval and test for the RIE effect are somewhat unclear a priori. Because RIE occurs after longer temporal lag between study and selective retrieval, RIE induces an interruption of time-dependent forgetting of the unpracticed information and can even eliminate the forgetting that has accumulated since study (see Fig. 5). However, it is unclear whether the interruption represents a short-lived or a lasting effect on recall performance. The interruption may be transient in character, with the recall level of the unpracticed information quickly

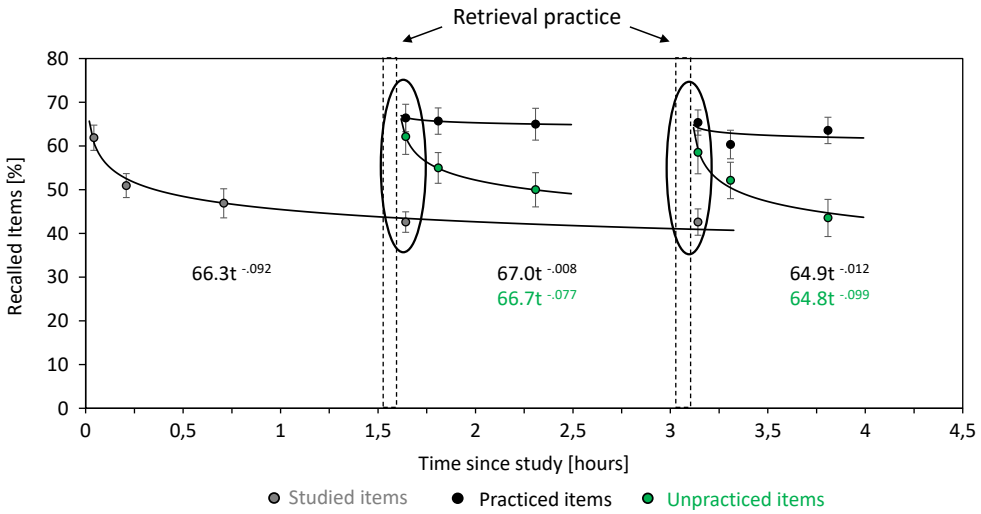

Fig. 7 Comparison of time-dependent forgetting of studied information immediately after study (studied items) and after time-lagged retrieval practice (practiced and unpracticed items). All three item types showed time-dependent forgetting, described by a power function of time. Immediately after retrieval practice, recall of both practiced and unpracticed items was enhanced relative to recall of studied items (highlighted by *ovals*). Studied and unpracticed items showed similar forgetting rates, whereas the forgetting rate of practiced items was reduced relative to the other items. *Error bars* represent standard errors. Adapted from Bäuml K-HT and Trißl L (2022) Selective memory retrieval can revive forgotten memories. Proceedings of the National Academy of Sciences of the United States of America 119(8): e2114377119.

returning to the original course of forgetting soon after the selective retrieval. This would be the case if context retrieval made study context available for a short time after retrieval only so that RIE would merely reflect a transient discontinuity in the stream of temporal context (Folkerts et al., 2018). However, the interruption may also be more permanent in character and, for instance, be accompanied by a restart of time-dependent forgetting. This would be the case if context retrieval induced an updating of context that permanently shifted the study context closer to the retrieval context. The induced restart of time-dependent forgetting would then make time-dependent forgetting after retrieval similar to initial time-dependent forgetting after study and thus induce a complete reset of recall for these memory contents—creating lasting RIE.

Bäuml and Trißl (2022) addressed the issue in three experiments, in which participants studied either lists of unrelated items or a coherent prose passage. In each experiment, time-dependent forgetting of studied items when recall was tested after study in the absence of selective retrieval was compared with time-dependent forgetting of practiced and unpracticed items when recall was tested after selective retrieval. Across experiments, retrieval practice occurred 30 min, 90 min, 2 h, or 3 h after study. Both when recall was tested after study in the absence of retrieval practice and when it was tested after retrieval practice, recall was assessed at different delay intervals, which allowed a comparison of the time-dependent forgetting before and after selective retrieval. To quantify forgetting over time, power functions of time were fit to the recall rates (Rubin and Wenzel, 1996; Wixted and Ebbesen, 1991). The resulting estimates of forgetting rates were then compared between experimental conditions. Results showed that retrieval practice enhanced recall of the unpracticed items and created a recall level for these items that was indistinguishable from the recall level of studied items shortly after study, which suggests that selective retrieval largely eliminated the forgetting that had accumulated since study. Critically, for all four employed lag conditions, forgetting rates after selective retrieval did not differ from forgetting rates after study (see Fig. 7), indicating that selective retrieval induced a reset of forgetting over time. The findings support the view that selective retrieval is accompanied by a permanent updating of temporal context.

While the findings by Bäuml and Trißl (2022) demonstrate lasting effects of RIE, they do not imply that RIE will still be present if very long delay intervals, like several weeks, between selective retrieval and test are employed. Rather, the findings suggest that the size of the RIE effect will decline more and more as the delay interval between selective retrieval and test increases. This prediction of an increasing decline of the effect follows naturally if studied and unpracticed items show comparable and typical time-dependent forgetting. In such a case, recall of the studied items will undergo a high degree of forgetting soon after study but show a moderate decline only with the further passage of time—and thus also after the time when time-lagged selective retrieval occurs for the practiced and unpracticed items. In contrast, if unpracticed items show similar time-dependent forgetting after selective retrieval as the studied items show directly after study, then recall of the unpracticed information will decline rapidly soon after the selective retrieval, which will necessarily reduce the size of RIE (see Fig. 7). The recall boost induced by selective retrieval should therefore be highest right after the selective retrieval and then gradually attenuate as delay increases. Wallner et al. (2022) provided support for this prediction.

4.5 Boundary conditions of RIE

Boundary conditions of RIE have hardly been investigated to date. As outlined in Section 4.4, very long delay between selective retrieval and test is likely to represent a boundary condition of RIE. Two further boundary conditions have been identified in recent work. The one boundary condition was reported by Wallner and Bäuml (2017), demonstrating that RIE can turn into RIF if immediately preceding the retrieval phase, study context is mentally reinstated. Wallner and Bäuml (2017) employed the output-order task with selective retrieval being time-lagged by 10 min. There were mental-context-reinstatement and no-mental-context-reinstatement conditions. In the mental-context-reinstatement condition, subjects immediately before the retrieval phase were told to take a minute to recall their thoughts, feelings, and emotions prior to the beginning of the study phase, whereas in the no-mental-context-reinstatement condition, subjects solved arithmetic problems for the same duration of time. As expected, RIE was observed in the no-mental-context-reinstatement condition. However, in the mental-context-reinstatement condition, RIF arose, suggesting that the preceding mental context reinstatement made further, subsequent context retrieval obsolete. Preceding reinstatement of study context not only may arise through deliberate active reinstatement attempts but also may occur unintentionally, for instance, if an encoded event included particularly salient, exceptional, or emotional features. For example, once again seeing pictures of the storming of the United States Capitol on January, 6th, 2021, may immediately reinstate the context that one was in while becoming aware of the riots, reducing the likelihood of further retrieval-induced context retrieval.

Category labels presented during initial study of unrelated items may do a similar job if reexposed during retrieval, as indicated by results of Wirth and Bäuml (2020). These researchers used the output-order task and lists of unrelated items as study material to examine whether the RIE effect generalized to a condition in which the items were not studied in isolation—which is the typical procedure in memory experiments with unrelated items—but were studied together with their category labels (e.g., BIRD-magpie), with the category labels being reexposed as cues during retrieval (e.g., BIRD-m___). Using a 15-min lag interval between study and retrieval, the researchers replicated the RIE effect if the items had been studied in isolation in the absence of category labels and no category labels were provided during retrieval. In contrast, they found a RIF effect if the items were studied together with their category labels and these labels were reexposed as cues during retrieval. These findings are consistent with the view that, if the items are studied together with their category labels, reexposure of the category labels during retrieval can reinstate study context after longer lag, making context retrieval obsolete and turning the RIE effect into RIF (see also MacLeod and Macrae, 2001). Thus, context reinstatement preceding selective retrieval can serve as a boundary condition of the RIE effect, regardless of whether study context is mentally reinstated or is reinstated through reexposure of salient features encoded during study.

4.6 Summary of the findings

Time-lagged selective retrieval can induce recall enhancement on the unpracticed information. Such RIE has been observed for word lists as well as prose passages and for lag intervals between 10 min and 7 days. The effect arises in response to both selective retrieval and selective restudy and thus is not retrieval specific, although it is generally larger in response to retrieval. RIE is a lasting effect and accompanied by a restart of time-dependent forgetting, as is reflected by the fact that forgetting after selective retrieval is similar to forgetting after study in the absence of selective retrieval. RIE has been attributed to context retrieval, according to which retrieval of an item results in a partial reactivation of the context that was present when that item was studied. This retrieved context then serves as a retrieval cue for other items with a similar context at study, facilitating recall of these items. The reported findings are consistent with this account. In particular, they indicate that context retrieval induces a permanent updating of temporal context.

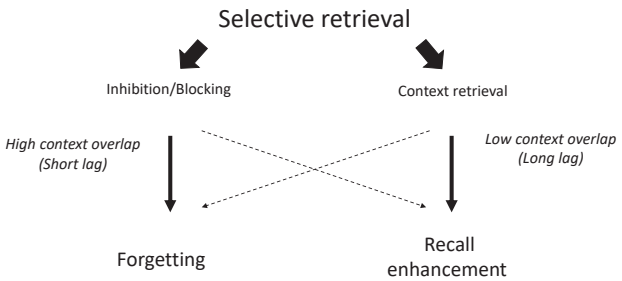

Fig. 8 Account of the effects of selective retrieval on unpracticed items. The account assumes that selective retrieval generally triggers inhibition and blocking as well as context retrieval processes. The relative contribution of the two types of processes is supposed to depend on the contextual overlap between study and retrieval. When the overlap is high — such as after short temporal lag between study and selective retrieval — the relative contribution of inhibition and blocking is assumed to be larger than that of context retrieval, thus inducing forgetting of unpracticed items. In contrast, when the contextual overlap is low — such as after longer lag between study and selective retrieval — the relative contribution of context retrieval is assumed to be larger than that of inhibition and blocking, inducing recall enhancement of unpracticed items.

5 A theoretical framework and possible applications

5.1 The two faces of selective retrieval

The results on the detrimental and beneficial effects of selective retrieval reported in preceding Section 3 and preceding Section 4 suggest that there are two faces of selective memory retrieval. Depending on whether selective retrieval follows immediately after encoding or is time-lagged, it can induce a detrimental or beneficial effect on the unpracticed information. This pattern of results has been explained by a two-factor account of selective retrieval (see Bäuml, 2019). According to this account, inhibition and blocking as well as context retrieval contribute to the effects of selective retrieval. When retrieval practice follows shortly after study and temporal context is still similar to study context, recall cannot benefit much from context retrieval but inhibition and blocking operate in response to retrieval practice, causing forgetting of the unpracticed items. In contrast, as time after study passes and context gets more and more dissimilar to study context, retrieval of the practiced items triggers context retrieval, which reinstates study context and enhances recall of the unpracticed items. The recall enhancement may also benefit from a reduction of interference between items with increasing lag (Kliegl et al., 2019) so that the contributions of inhibition and blocking to recall attenuate and beneficial effects on recall induced by context retrieval manifest themselves more easily (see Fig. 8).

This two-factor account can explain the presence of detrimental effects of selective retrieval when selective retrieval occurs immediately after study as well as the presence of beneficial effects when selective retrieval is time-lagged. Moreover, the account suggests that RIF can evolve into RIE when temporal lag between study and retrieval practice is gradually increased from short to longer temporal lag, thus gradually reducing the contextual overlap between study and retrieval and increasing the contribution of context retrieval. In such case, the forgetting effect observed shortly after study should first turn into a neutral effect of retrieval practice and then into recall enhancement.

This prediction was examined in a recent study that used the retrieval practice task and employed a 2-min delay between selective retrieval and test (Kriechbaum and Bäuml, 2023). The recall of unpracticed items after retrieval practice was compared with the recall of control items when an unrelated distractor task rather than retrieval practice preceded the recall test (see Fig. 4A). Recall of unpracticed and control items was compared for a short 2-min and a longer 20-min lag between study and retrieval practice as well as intermediate lag intervals between 8 and 14 min. The results of two experiments showed the predicted gradual transition from RIF to RIE (see Fig. 9). Typical RIF emerged when retrieval practice occurred 2 min after study, but the forgetting quickly disappeared when temporal lag between study and retrieval practice was increased. In fact, recall of the unpracticed items was more or less unaffected by retrieval practice when practice took place between 8 and 14 min after study, and 20 min after study retrieval practice already led to recall enhancement. Critically, the enhancement observed 20 min after study was sufficiently strong to eliminate the forgetting over time that had accumulated since study, which indicates that inhibition and blocking barely contributed to recall at this point in time. The findings are consistent with the view that retrieval practice caused mainly inhibition and blocking shortly after study, and mainly context retrieval about 20 min later.

In the Kriechbaum and Bäuml (2023) study, different distractor tasks were employed across experiments to fill the temporal lags between study and selective retrieval, which, however, did not influence the transition from RIF to RIE. Nevertheless, in general, type of distractor should affect results to some degree. For instance, if, during the temporal lag, participants were engaged in daydreaming tasks, which are known to enhance internal context change (Delaney et al., 2010), then context retrieval may play a stronger role for recall than it did in the absence of such tasks and RIE arise also for lags shorter than 20 min. Indeed, Wallner and Bäuml (2017)

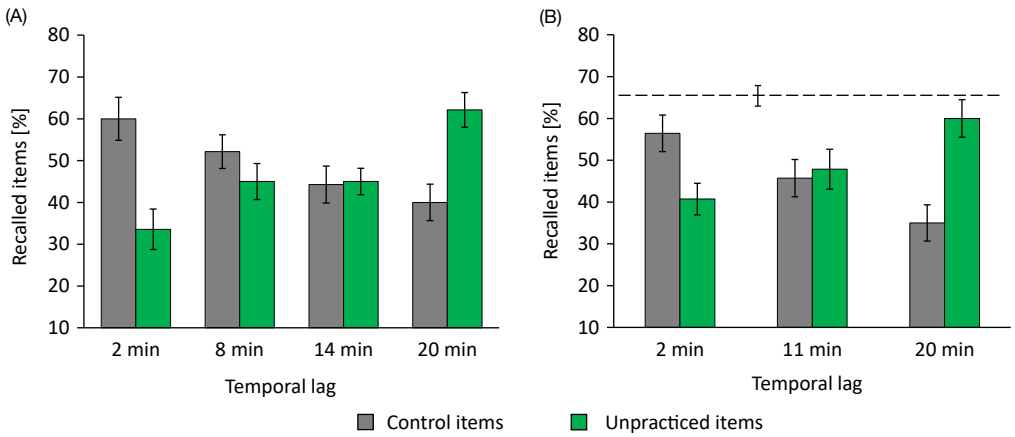

Fig. 9 Comparison of recall rates of control items and unpracticed items as a function of temporal lag between study and retrieval practice. (A), (B) Recall of control items decreased but recall of unpracticed items increased from the shorter to the longer temporal lag conditions. After the short 2-min lag, recall of control items was superior to recall of unpracticed items; after the longer 20-min lag, the pattern reversed and recall of unpracticed items was superior to recall of control items; recall of the two item types was similar in the intermediate lag conditions. The *dashed line* in (B) represents recall of control items when these items were tested immediately after study. *Error bars* represent standard errors. Panels (A) and (B): Adapted from Kriechbaum VM and Bäuml K-HT (2023) The critical importance of timing of retrieval practice for the fate of nonretrieved memories. Scientific Reports 13(1): 6128.

reported beneficial effects of selective retrieval for temporal lags of 10 min when the output-order task was employed and participants engaged in daydreaming tasks during the 10-min lags (see Section 4.1). Because Kriechbaum and Bäuml (2023) employed the retrieval practice task that did not include any daydreaming tasks as distractor and did not find RIE for lags shorter than 20 min, the findings by Wallner and Bäuml (2017) are in line with the view that type of distractor can influence the transition from RIF to RIE.

5.2 Selective "versus" comprehensive retrieval practice

The two-factor account explained in preceding Section 5.1 focuses on selective retrieval and the fate of the unpracticed information. In consequence, it is silent about the effects of selective retrieval on the practiced information. However, assuming that retrieval practice affects the practiced information largely independent from whether all studied information is practiced or a subset of the information is practiced only, the two-factor account may be enriched by including accounts of the testing effect to explain how selective retrieval practice influences recall of the practiced information. Depending on view, one may thus propose that retrieval practice leads to a particularly high level of strengthening of the successfully practiced material (Kornell et al., 2011), an enhanced elaboration of the practiced material (Carpenter, 2009), or a richer contextual representation for the practiced material (Karpicke, 2017; see Section 2.1). Each view would provide an integration of theoretical accounts of selective and comprehensive retrieval practice.

Selective retrieval shortly after study and comprehensive retrieval practice typically differ in effects on recall performance, because comprehensive retrieval may improve recall of most studied items, whereas selective retrieval improves recall of some studied items (the practiced items) but impairs recall of the other items (the unpracticed items). In contrast, time-lagged selective retrieval shows more similarities to the effects of comprehensive retrieval practice. It can improve recall of both the practiced and the unpracticed items, and, intriguingly, can even induce beneficial effects of similar size for the two types of items (see Section 4.1). On the basis of these findings, in applications, one may thus prefer selective over comprehensive retrieval practice when practice is lagged, given that the two forms of practice can induce quite similar beneficial effects, but retrieval practice on some items is more time-saving than retrieval practice on all studied items.

However, there is an important difference between the beneficial effects caused by (time-lagged) selective and comprehensive retrieval practice. Whereas comprehensive retrieval practice typically reduces subsequent time-dependent forgetting of the practiced items—and thus of most studied items—selective retrieval practice reduces subsequent time-dependent forgetting of the practiced items, but not the unpracticed items (see Fig. 7). Indeed, the unpracticed items show relatively "normal" subsequent forgetting over time, which reduces the size of the beneficial effect for the unpracticed items as more and more time after retrieval practice passes (see Section 4.4). In effect, time-lagged selective retrieval will thus reduce time-dependent forgetting for some items (the practiced items) but not for the other items (the unpracticed items), indicating that at least for longer delay between practice and test, comprehensive retrieval practice will lead to greater benefits on recall than time-lagged selective retrieval practice.

5.3 Further demonstrations of beneficial effects of selective retrieval

According to the two-factor account of the effects of selective retrieval, the contextual overlap between study and selective retrieval is the critical factor on whether selective retrieval induces forgetting or recall enhancement on the unpracticed information. The temporal lag between study and retrieval practice typically influences this overlap and thus influences the effects of selective retrieval. However, other factors may also influence this overlap, like, for instance, directed forgetting of studied information. In list-method directed forgetting, participants are given two lists of unrelated items for study. Between study of the two lists, participants receive a cue to either forget or continue remembering the items of the first list. Shortly after study of the second list, recall of first-list items is tested (Bjork, 1970). The typical finding is that recall of first-list items is reduced in the forget condition relative to the remember condition, which has often been attributed to impaired context access for first-list items in response to the forget cue (Geiselman et al., 1983; Sahakyan and Kelley, 2002).

Bäuml and Samenieh (2010) examined the effects of selective retrieval in list-method directed forgetting. The study followed the standard procedure of this form of directed forgetting, but used the output-order task at test. Thus, the focus was on recall of predefined target items from the first list: Participants at test were asked either to recall the target items first or to recall some of the list's remaining items first and the target items second. In the remember condition, preceding recall of the list's other items reduced recall of the target items, relative to the condition, in which the target items were recalled first, thus showing RIF. In contrast, in the forget condition, preceding recall of the list's other items enhanced recall of the target items, relative to the condition, in which the target items were recalled first, thus showing RIE. The findings thus mimic the effects of selective retrieval after short and prolonged temporal lag between study and selective retrieval, which is consistent with the view that both prolonged lag and a forget cue can reduce the contextual overlap between study and retrieval.

Bäuml and Dobler (2015) provided further evidence that, under certain circumstances, the presentation of remember and forget cues can simulate the influence of temporal lag on retrieval practice effects. Following Bäuml and Samenieh (2010), Bäuml and Dobler (2015) asked participants to study two lists of items and provided either a remember or a forget cue after study of the first list. At test, predefined target items from the first list were tested and it was manipulated whether target items were tested first, after prior recall of the list's remaining items, or after prior restudy of the list's remaining items—thus addressing the issue of retrieval specificity. In the remember condition, results supported retrieval specificity of RIF by showing that prior recall, but not prior

restudy, of the list's remaining items impaired target recall relative to the control condition, in which target items were recalled first. In contrast, in the forget condition, both prior recall and prior restudy of the list's remaining items enhanced target recall, indicating RIE after selective retrieval and a RIE-like effect after selective restudy. The findings in the forget condition thus mimic findings after prolonged temporal lag (see Section 4.3) and support the view that the beneficial effect of selective retrieval practice on unpracticed items is not retrieval specific.

5.4 Possible applications

The findings reported in this chapter offer numerous suggestions for what might be considered when retrieval practice is applied in educational contexts. In such contexts, retrieval of encoded information will sometimes occur shortly after the first encounter with a topic at school or university, for instance, when the teacher asks a few questions about the topic she has just introduced to ascertain that she has been well understood by the students. If, in such a case, the teacher wants the students to retain as many of the previously presented pieces of information in memory as possible, she should make sure to cover more or less all relevant details with her questioning. Indeed, if she did not repeat these details with her questioning, the nonrepeated details may be remembered worse than if she had not asked questions about the topic in the first place.

However, it is probably more often the case that the retrieval of encoded information occurs some time after the initial exposure to a particular topic. For instance, a student may prepare for an exam and repeat the topic that was introduced to him in the course of the semester by asking himself questions about it while the textbook is closed. Even if his questions covered only a subset of the details, some of the remaining details may still become better recallable than without practice, thus leading to an effective review of a considerable part of the study material. Such selective retrieval practice may be most effective when it occurs immediately prior to an exam since it can make the practiced and unpracticed materials similarly recallable at the time of test (Wallner et al., 2022). When the exam takes place several days after practice, the student should bear in mind that only the practiced, but not the unpracticed, material may show attenuated forgetting over time.

Knowledge about the effects of retrieval of encoded information on both the practiced and the unpracticed information also appears relevant in a variety of other contexts besides educational settings, such as in the area of eyewitness testimony. When asking a witness immediately after she observed a crime, an investigator should make sure to ideally question on most crucial details, since details that were not reviewed may suffer from impaired recall in the future (Shaw et al., 1995). Selective questioning about the crime should be less harmful to the details that are not reviewed when the interrogation takes place some time after the event. However, comprehensive questioning may still be preferred if the witness later had to testify in front of a court, because only this type of questioning may ensure reduced forgetting over time for most of the critical details. Finally, retrieval of encoded information also comes into play in many everyday situations, like, for instance, family conversations during dinner, when all family members try to recapitulate episodes and experiences of the day. In all such situations, it may be helpful to know that retrieval can affect long-term retention—and how the effects depend on whether retrieval is selective or comprehensive and on whether it is immediate or time-lagged.

6 Conclusions

Retrieval is not a neutral event where encoded information is just read out from memory. Rather, retrieval changes memory and can cause powerful effects on recall performance, both on recall of the practiced and on recall of the unpracticed information. The effects of retrieval on the practiced information are typically beneficial, increasing recall performance regardless of whether retrieval is comprehensive or selective. The effects of selective retrieval on the unpracticed information can depend on when after encoding selective retrieval takes place. If selective retrieval is time-lagged, beneficial effects on recall of the unpracticed items can arise, whereas if selective retrieval occurs immediately after encoding, typically detrimental effects on recall emerge. These findings are important for memory theory, providing critical insights into how retrieval shapes memories. But the findings are also of relevance for daily life—be it in educational settings, eyewitness testimony situations, or many everyday situations. In all these cases, retrieval can influence recall of the practiced and, if selective, also influence recall of the unpracticed information.

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