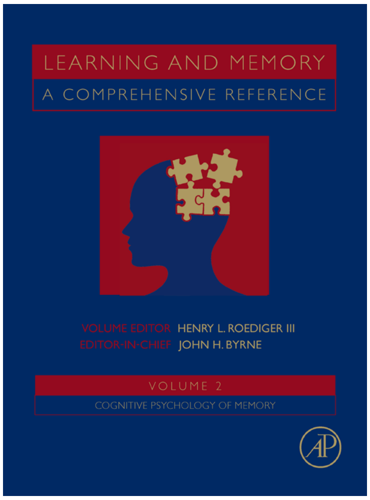

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2.13 Inhibitory Processes

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2.13.1 Introduction

2.13.1.1 Retrieval Competition

In the course of a day, we encounter a huge number of experiences that we encode and store in our memory. Some of these experiences may be unique and lead to the encoding of very distinct features. Most of the experiences, however, will share certain features with other experiences, thus leading to the encoding of common features in our memory. In his morning lecture, a professor, for instance, may encode many distinct features of each participating student while, for all students, encoding the common feature of participating in this particular course of study. The encoding of this common contextual feature can create a problem for the professor's memory when later asked about the names of the participating students. Typically, the larger the number of students who were present in the lecture, the poorer will be the professor's recall for any one particular name. The reason for this retrieval problem is retrieval competition.

Retrieval competition means that memories that share a common cue – be it a contextual, semantic, or emotional cue – compete for conscious recall once the cue is provided and, as a result, show both reduced recall performance and increased response latencies (Figure 1(a)). Corresponding evidence has been provided by a number of studies in quite different experimental paradigms. In single-list paradigms, for instance, memory for target information has been found to decline and to be slowed down when the number of list items increases, which is known as the list-length effect (Watkins, 1975). In multiple-list

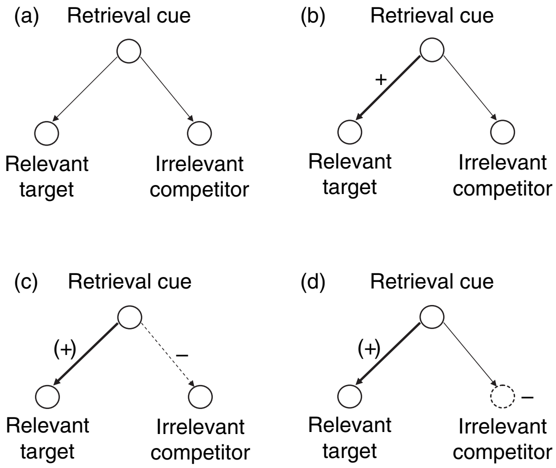

Figure 1 (a) Retrieval competition. Relevant target and irrelevant competitor material are connected to the same retrieval cue and compete for conscious recall once the cue is provided. For both materials, the competition reduces recall probability and increases response latency. (b) Blocking. Strengthened target information blocks access to nonstrengthened competitor information. Blocking occurs at test when the strengthened material is recalled first and hinders subsequent recall of the nonstrengthened material. Blocking does not affect the competitor's retrieval route and does not affect its memory representation. (c) Route deactivation. Deactivation of the retrieval route between cue and competitor information (with possible simultaneous enhancement of retrieval route between cue and target). Route deactivation takes place at a pretest encoding or a pretest retrieval stage and reduces chances of the retrieval cue to make competitor information recoverable. (d) Item suppression. Deactivation of the memory representation of the competitor information (with possible simultaneous enhancement of retrieval route between cue and target). Item suppression takes place at a pretest encoding or a pretest retrieval stage and reduces chances to recover the competitor information, regardless of which retrieval cue is provided.

paradigms, it has been shown that both the prior and the subsequent encoding of additional lists of items can impair memory for the target list, which is known as proactive and retroactive interference (Müller and Pilzecker, 1900; Underwood, 1957; for a summary, see Crowder, 1976).

Retrieval competition provides a challenge for the goal-directed use of memory. Indeed, in daily life, relevant and irrelevant information often share a common cue. This may be the case for the more relevant and more irrelevant things that occurred to us in the office, the expired and current passwords of our computer, or the past and current address of a friend's home. When trying to recall the relevant or current information, remembering then may fail because the irrelevant or out-of-date information is retrieved. Effective updating should reduce accessibility of the irrelevant memories and simultaneously enhance that of the more relevant information.

It is an old and prominent idea that, in our memory, inhibitory processes operate to serve the function of goal-directed remembering, reducing the accessibility of irrelevant information and enhancing that of the more relevant information. In this chapter, I summarize results from a number of experimental paradigms in which the action of inhibitory processes serving memory's goal-directed use has been suggested. While there is consensus in the literature that inhibitory mechanisms operate to overcome retrieval competition and enhance the processing of relevant information, different conceptions about inhibitory mechanisms exist. In fact, some researchers speak of inhibition whenever a mechanism reduces accessibility of irrelevant information, be it directly or indirectly. Others speak of inhibition only if a mechanism affects the irrelevant information directly, be it through deactivation of the information itself or through deactivation of some of its retrieval routes.

The goal of this chapter is not to discuss which mechanism reflects real inhibition and which does not. Rather, the goal is to indicate which of the suggested mechanisms operate under what conditions. As it turns out, different mechanisms operate in different experimental contexts, providing us with a detailed picture of how reduced accessibility of irrelevant information is achieved in memory. Before reviewing these results, some of the most important conceptions of inhibitory processes suggested in the past decades are outlined. After becoming familiar with these conceptions, I turn to determining which of the inhibitory processes operates in which experimental context.

2.13.1.2 Inhibitory Mechanisms

Three primary inhibitory mechanisms have been suggested to serve the goal of effectively separating relevant from irrelevant information and enhancing memory for the first at the expense of the second. The three mechanisms are blocking, route deactivation, and item suppression.

1. Blocking

As described in section 2.13.1.1, when memories share a common cue, they compete for conscious recall once the cue is provided and show reduced recall performance (**Figure 1(a)**). Such retrieval competition has been shown to be strength dependent. That is, if material that is strongly represented in memory and material that is weakly represented share the same retrieval cue, there is a tendency for the stronger material to be recalled first (Rundus, 1973; Raaijmakers and Shiffrin, 1981; Wixted et al., 1997). Thus, if relevant material, like the current computer password, is represented more strongly in memory than irrelevant material, that is, the expired password, the difference can induce a competition bias at test favoring the early recall of the (stronger) relevant information – the current password. By involuntarily sampling the already recalled material repeatedly, this early recall of the relevant information then can block subsequent recall of the (weaker) irrelevant information – the expired password – and make it inaccessible (**Figure 1(b)**). Such blocking of irrelevant information has repeatedly been regarded as an important example of inhibition in human memory (Melton and Irwin, 1940; McGeoch, 1942; Rundus, 1973) and is a core feature of many computational models (Raaijmakers and Shiffrin, 1981; Mensink and Raaijmakers, 1988).

A crucial feature of blocking is that there is no direct effect of inhibition on the irrelevant material itself and no direct effect on the retrieval routes between the irrelevant material and its cue(s). Rather, the inaccessibility of the irrelevant material (the expired password) arises as a by-product of the strengthening of the relevant material (the current password), which, as a result of biased competition, favors recall of the stronger relevant material and blocks recall of the weaker irrelevant material. Because blocking typically operates at test, its effect should be visible in memory tests in which there is the opportunity for strength-dependent retrieval (i.e., in free recall tasks and in cued recall tasks in which more than one item is connected to the cue). In contrast, blocking should play only a minor role, if any, in memory tests in which item-specific probes are provided as retrieval cues, such as recognition tests or implicit memory tests. In all these tests, strength-dependent competition should be greatly reduced or eliminated.

2. Route deactivation

A more direct way to induce inaccessibility of irrelevant material would be to not only strengthen the relevant material but also weaken the retrieval route between the irrelevant information and its cue, so that retrieval of the irrelevant information becomes less effective (Melton and Irwin, 1940; Geiselman et al., 1983; **Figure 1(c)**). Applied to the computer password retrieval problem, this would mean that, rather than blocking retrieval of the expired computer password, an inhibitory mechanism would directly weaken the connection of the expired password's memory representation to the common password cue. Such route deactivation might operate while the new password is encoded, or it might operate after the encoding of the new password, for instance, when retrieving the current computer password. Because the retrieval routes to the irrelevant information would be affected directly, the effect of such a mechanism should be visible in a number of memory tests and should arise not just in free recall tasks but in all forms of cued recall as well. On the other hand, because the representation of the irrelevant material itself would not be affected, only minor, if any, forgetting of the irrelevant information should be observed in recognition tasks.

The strengthening of relevant information creates a difference in relative strength between relevant and irrelevant information and thus can lead to blocking. Route deactivation also creates a difference in relative strength, which may be particularly strong, if not only the retrieval routes for the irrelevant material are reduced but retrieval routes for the relevant material are simultaneously enhanced. Therefore, route deactivation may trigger blocking at test as an additional mechanism, an effect that should be largely restricted to free recall tasks.

3. Item suppression

Blocking and route deactivation reflect mechanisms that, following Tulving and colleagues' terminology (Tulving and Pearlstone, 1966; Tulving and Psotka, 1971; Tulving, 1974), result in loss of retrieval access to inhibited items rather than in loss of the items' availability. A loss in availability would imply that the memory representation of material is affected itself so that memory for the material is impaired regardless of which retrieval cue is provided. It has repeatedly been suggested that inhibitory processes may affect the item representation itself (Postman et al., 1968; Anderson and Spellman, 1995; **Figure 1(d)**). Applied to the computer password retrieval problem, for instance, this would mean that, rather than blocking the expired computer password or reducing its connection to the common password cue, the memory representation of the expired password would directly be suppressed. Such suppression might operate while the new password is encoded, or it might operate after the encoding of the new password, for instance, when retrieving the current computer password. Due to the direct effect on the memory representation of the irrelevant information itself, item suppression would reflect a strong form of inhibition and should be visible over a wide range of memory tests, including recognition tasks and tasks that employ so-called independent probes, that is, probes not used until the test phase of an experiment.

Like route deactivation, a side effect of item suppression is that a difference in relative strength between relevant and irrelevant material is created, particularly if there is simultaneous strengthening of the relevant information. In memory tests that are sensible to strength-dependence effects, this difference can trigger blocking as an additional inhibitory mechanism. In free-recall tasks, item suppression, therefore, may reduce accessibility of irrelevant material very effectively.

In sum, although blocking, route deactivation, and item suppression can all serve the goal of reducing accessibility of irrelevant material and enhancing that of relevant information, the three mechanisms differ in the way the inaccessibility is achieved. In blocking, the inaccessibility arises because of the difference in relative strength between target and competitor information, with early recall of the stronger target information blocking recall of the weaker competitor information; in route deactivation, inaccessibility arises because of the direct deactivation of the retrieval route between the cue and the irrelevant information; and in item suppression, inaccessibility arises because of the direct deactivation of the memory representation of the irrelevant material itself, which, following Tulving's terminology, represents some form of information unavailability.

The difference in how inaccessibility is achieved in the three inhibitory mechanisms has implications for the range of memory tests in which the effects of inhibition can be observed. Blocking represents the weakest form of inhibition. Because it does not affect the irrelevant material directly, its effects should arise only in memory tests that leave sufficient room for strength-dependent retrieval, like free-recall tasks. By directly affecting the retrieval routes to the irrelevant material, route deactivation represents a stronger form of inhibition, the effects of which should be observable in free-recall and cued-recall tasks. Item suppression, finally, represents the strongest form of inhibition that affects the memory representation of the inhibited item itself and thus should create effects across a wide range of memory tests. Also note that route deactivation and item suppression can trigger additional blocking at test, thus creating a situation in which two inhibitory processes may operate in concert.

The next section examines the role of the three suggested inhibitory mechanisms in experimental paradigms that are often assumed to involve inhibition: strength-induced forgetting, retrieval-induced forgetting, directed forgetting, think/no-think impairment, and part-list cuing impairment. At the end of the section, current knowledge about the developmental trajectory of inhibition in the single paradigms is reviewed. In the conclusion, finally, the results are summarized and a taxonomy of the inhibitory paradigms is suggested.

2.13.2 Inhibitory Paradigms

2.13.2.1 Strength-Induced Forgetting

A simple way to emphasize memory for relevant material is to present the relevant information repeatedly or longer and the less relevant information less often or for a shorter time period. This is common use in textbooks or talks, in which important information is typically repeated in several places, and it is typically employed by students preparing for an exam, when they spend more time on the seemingly relevant material than on the seemingly irrelevant material.

Strengthening the memory representation of relevant information – be it through repeated or longer study – should lead to different memory performance for the relevant and irrelevant information, simply because of the resulting difference in (absolute) memory strength between the two types of information. The effect of strengthening or inhibition that we observe in experiments, however, is often larger than we might expect on the basis of the encoding difference, suggesting that additional processes enhance accessibility of the relevant material and reduce it for irrelevant material. This point has been demonstrated in a number of experimental paradigms, discussed next. In these paradigms, a subset of the material to be learned is strengthened, and its effect on later memory for the strengthened and non-strengthened material is examined.

2.13.2.1.1 The mixed-list paradigm

In the mixed-list paradigm, participants are presented a list of items such as unrelated words. Strengthening effects are then examined by providing a longer presentation time for a subset of the material or by presenting a subset of the material repeatedly (e.g., Tulving and Hastie, 1972; **Figure 2**). For instance, half of the items of a list may be shown for 6 s and the other half for 2 s, or half of the items may be shown twice and the other half once. Memory performance for the two types of items is compared with two pure-list baseline conditions in which there is no such partial strengthening and all material is studied in the same way (i.e., all items are studied for 6 s or all items are studied for 2 s). Memory is typically assessed by means of a free-recall test, a cued-recall test, or a recognition test.

On the basis of the encoding difference between strong and weak items, strong items should show better memory than weak items. In particular, strong items in mixed lists should show the same memory performance as strong items in pure lists, and weak items in mixed lists should show the same performance as weak items in pure lists. The general idea of retrieval competition and blocking, as outlined above (in sections 2.13.1.1 and 2.13.1.2), however, suggests otherwise, at least in free-recall tasks. Partial strengthening in the mixed-list paradigm should introduce a competition bias, leading to early recall of the strengthened items, which then may block subsequent recall of the nonstrengthened items. As a result, on average, strong items in mixed lists should show better performance than strong items in pure lists, and weak items in mixed lists should show poorer performance than weak items in pure lists. Such effects should be present in free-recall tasks, but they should be absent in recognition tasks, in which no such competition bias is expected.

Indeed, free-recall experiments have shown that, in mixed lists, strengthened items are better recalled than nonstrengthened ones and that this effect is not only a result of the difference in the items' absolute memory strength but is also attributable to their difference in relative strength. Recall of strong items was consistently found to be higher in mixed lists than in pure lists, and recall of weak items was

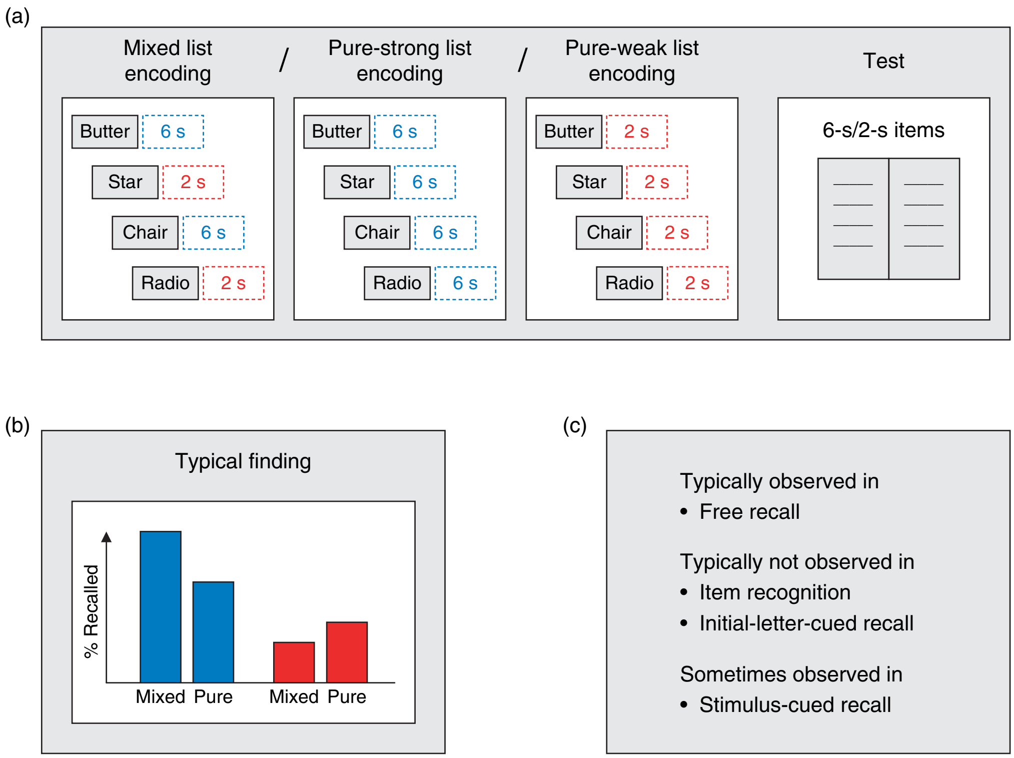

Figure 2 The list-strength effect. (a) The experimental paradigm. Participants study a mixed list consisting of strong and weak items. Memory for the two types of items on a later test is compared to two baseline conditions: a pure-strong list condition containing strong items only and a pure-weak list condition containing weak items only. Strengthening is accomplished by varying either the exposure time or the number of repetitions of the items to be strengthened. (b) The typical finding. Relatively more strong items are recalled from the mixed list than from the pure-strong list, and relatively fewer weak items are recalled from the mixed list than from the pure-weak list. (c) Memory tests. Examples of memory tests in which the list-strength effect typically arises and in which it typically does not arise.

found to be poorer in mixed lists than in pure lists (Tulving and Hastie, 1972; Ratcliff et al., 1990; see also Malmberg and Shiffrin, 2005). In contrast, such list-strength effects have typically been found to be absent in recognition tasks. Although recognition of strong items was found to be higher than recognition of weak items, performance for the two types of items did not vary with list composition (Ratcliff et al., 1990; Murnane and Shiffrin, 1991; Ratcliff et al., 1992).

A few studies reported reliable recognition effects in the mixed-list paradigm (see Norman, 2002, for item recognition, and Verde and Rotello, 2004, for associative recognition), which were used to draw inferences on whether the effects were caused by changes in recollection or changes in the familiarity of the items. Tulving (1985) distinguished between two bases for judging an item as 'old' on a recognition test: The participant specifically remembers the temporal and/or spatial context in which the item was studied (recollection), or the participant finds the item just familiar (familiarity; for a review, see Yonelinas, 2002). From the studies reporting reliable list-strength effects in recognition, evidence has arisen that the list-strength effect reflects mainly a modulation in recollection but does not affect familiarity.

A number of studies examined list-strength effects in cued recall. In paired-associate learning with stimulus-cued recall tests, a mixed picture arose with reliable effects in some experiments and nonreliable ones in others (Ratcliff et al., 1990). List-strength effects were also examined when categorized lists were studied. In this case, each category studied was a mixed category, with half of the items being strong (high-frequency) exemplars and half of the items weak (low-frequency) exemplars of the category, or a pure category, with all items being strong exemplars or all items weak exemplars. The items' category name and their unique initial letters were provided as retrieval cues at test. Performance of strong and weak items was compared between mixed categories and pure categories when the items were tested first within their categories, thus controlling for possible effects of output order. For both strong and weak items, no effect of category composition arose (Bäuml, 1997).

As a whole, these findings are largely consistent with the proposal that strengthening, as employed in the mixed-list paradigm, leads to blocking at test, which improves access to the relevant information at the expense of the access to the irrelevant material. Accordingly, the list-strength effect is typically present in free-recall tasks and is absent in recognition tasks. If output order is controlled, the effect is also absent in cued-recall tasks, which is consistent with the view that the inhibitory mechanism does not affect the items' retrieval routes or their memory representation.

2.13.2.1.2 Relearning and interference paradigms

Findings consistent with those from the mixed-list paradigm have been reported in two further strengthening paradigms, relearning and interference. In the relearning paradigm, strengthening effects are examined by presenting the relevant and irrelevant material together within one list and subsequently presenting the relevant material again for an additional study trial. This relearning condition is then compared with a condition in which there is no such reexposure of the relevant material.

Again, the idea of blocking suggests that, at least in free-recall tasks, retrieval competition may become biased because of the strengthening of a subset of the material and thus may increase recall of the relearned material at the expense of the material presented only once. Such effects, however, should not arise in recognition tests or tests using item-specific probes. A number of studies examined this latter prediction in cued-recall tests, in which the items' unique initial letters were provided as additional retrieval cues and output order was controlled by testing the target items first. In all these studies, relearning improved recall of the strengthened material but did not affect recall of the nonstrengthened material (Ciranni and Shimamura, 1999; Anderson et al., 2000a; Bäuml and Aslan, 2004). This finding is consistent with the assumption that strength-induced forgetting is mediated by blocking rather than by deactivation of retrieval routes or by deactivation of the item representation.

Both in retroactive and proactive interference, older studies had shown that strengthening of prior or subsequently encoded material can increase interference and thus increase forgetting of target material (for a review, see Crowder, 1976). Varying the degree of interpolated learning in a list-learning paradigm, Bäuml (1996) replicated this result and found that a higher degree of interpolated learning induced greater retroactive interference. In this experiment, output order was not controlled, and participants were free to recall the strengthened interpolated material prior to the (weaker) target material. In a second experiment, which was largely identical to the first experiment, output order was controlled, and participants were asked to recall the (weaker) target material first. No effect of degree of interpolated learning was observed (for a related result regarding proactive interference, see DaPolito, 1966; for further investigation, see Delprado, 2005). Again, these findings point to the action of a blocking mechanism, which is activated in memory tests that permit recall of items in any order.

2.13.2.1.3 Summary

Results from paradigms investigating strength-induced forgetting indicate that the strengthening of relevant material at encoding can trigger inhibitory processes to improve memory for the strengthened material at the expense of that for the not strengthened or irrelevant material. Strength-induced forgetting is present in free-recall tests and absent in recognition tests or cued-recall tests, in which output order is controlled. These results are consistent with the proposal that the enhanced accessibility of strengthened material and the reduced accessibility of nonstrengthened material result from blocking at test, in which early recall of stronger items prevents subsequent recall of the weaker ones. The results do not support the idea that the memory effects in these paradigms are caused by direct inhibitory effects on the irrelevant material's representation or its retrieval routes.

2.13.2.2 Retrieval-Induced Forgetting

The strengthening of relevant material at encoding can trigger inhibitory processes on the nonstrengthened irrelevant material. Strengthening of relevant material, however, does not only occur at encoding but may happen through retrieval as well. In fact, while relearning is an often employed method to emphasize memory for relevant material, retrieval of previously studied material can serve the same goal. One may even expect to find strengthening through retrieval to induce the same inhibitory processes as strengthening at encoding.

Experimental studies have shown that retrieval typically enhances later recall of the practiced material (Hogan and Kintsch, 1971) and can even be more powerful in its effect than relearning is (Carrier and Pashler, 1992; Roediger and Karpicke, 2006). The question arises of whether strengthening through retrieval also induces inhibitory processes and, if it does, whether such inhibition is mediated by the same competition bias as the inhibition underlying strengthening through relearning. On the basis of many computational models of memory, this might be expected, given that retrieval has often been assumed to reflect some form of relearning (e.g., Rundus, 1973; Raaijmakers and Shiffrin, 1981).

2.13.2.2.1 Retrieval-practice paradigm

In the retrieval-practice paradigm, a subset of learned material is repeatedly retrieved, and the effect of this manipulation on later memory for the practiced and unpracticed material is examined (Anderson et al., 1994; **Figure 3**). Memory is typically assessed by means of free recall, cued recall, and recognition tests. In addition, so-called independent probe tests are conducted, in which memory is assessed using cues at test that were not employed in earlier parts of the experiment. On the basis of retrieval competition and blocking, it might be assumed that retrieval simply strengthens the practiced material and thus causes blocking for the unpracticed material. Such blocking would increase recall for the practiced material and decrease recall for the unpracticed material, relative to control items in a no-practice condition. If true, then the effect of retrieval would mimic the effect of relearning.

A large number of free- and cued-recall experiments have addressed this issue in recent years. In these experiments, participants often learned categorized item lists and then practiced half of the items from half of the categories. At test, the category names were then provided as retrieval cues and the task was to recall the previously studied items that belonged to the category name. Relative to the control items from the unpracticed categories, retrieval practice typically improved recall of the practiced items and impaired that of the unpracticed items from the practiced categories (Anderson et al., 1994; Anderson and Spellman, 1995; Macrae and MacLeod, 1999; MacLeod and Macrae, 2001; Bäuml and Hartinger, 2002). This pattern of results first of all mirrors the beneficial and detrimental effects of strengthening at encoding, suggesting that the effect may be a result of blocking.

If the effects of retrieval were equivalent to those of relearning and only reflected biased competition and blocking, the detrimental effects of retrieval practice should be eliminated once item-specific probes were employed at test and output order was controlled. The issue was examined in experiments in which the detrimental effects of relearning and retrieval were compared directly. Participants learned categorized lists. At test, the category names

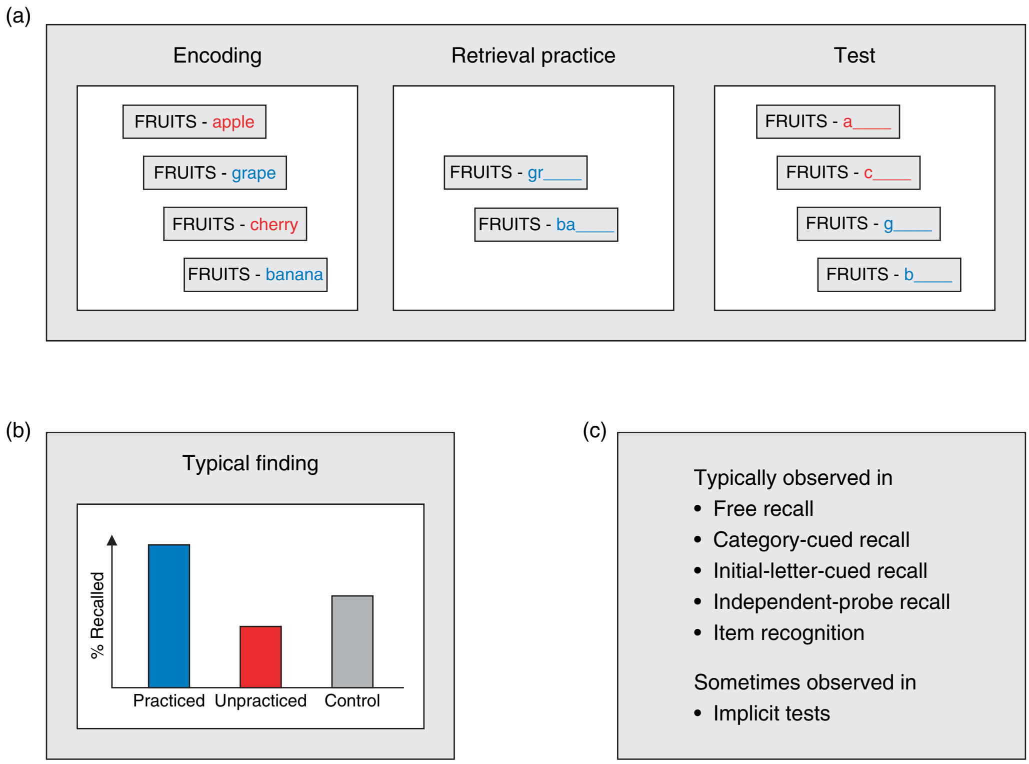

Figure 3 Retrieval-induced forgetting. (a) The experimental paradigm. Participants study a categorized item list. In a subsequent retrieval-practice phase, half of the items from half of the studied categories are repeatedly retrieved. On the final test, participants are asked to recall all previously studied items. (b) The typical finding. Practiced items show higher recall rates, and unpracticed items show lower recall rates relative to the control items from the unpracticed categories. (c) Memory tests. Examples of memory tests in which retrieval-induced forgetting typically arises.

and the targets' initial letters were provided as retrieval cues. To control for output order, the targets were always tested first within their categories. Consistent with the results from the strengthening paradigms, no detrimental effect of relearning arose. In contrast, reliable forgetting arose in the retrieval practice condition (Anderson et al., 2000a), indicating that retrieval-induced forgetting reflects a recall-specific effect and is not caused by blocking (for related results, see Ciranni and Shimamura, 1999; Bäuml, 2002).

Further studies support the proposal that retrieval-induced forgetting does not reflect blocking by showing that the effect is not only present in free and category-cued recall but occurs in other types of tests as well. Using the so-called independent probe procedure, for instance, retrieval-induced forgetting has been reported to be cue independent, that is, to generalize to cues other than those used at study or retrieval practice (Anderson and Spellman, 1995; Anderson et al., 2000b; Saunders and MacLeod, 2006; Aslan et al., 2007b). Accordingly, retrieval practice of 'fruit-apple' was found to induce forgetting of 'banana' not only when banana was tested with the same cue as was used at study and retrieval practice ('fruit') but also when it was probed with a new, independent cue (e.g., 'monkey'). This property of cue independence is taken as strong support for the view that retrieval-induced forgetting is caused by inhibition (Anderson, 2003; for failures to find cue independence, see Williams and Zacks, 2001; Perfect et al., 2004).

Retrieval-induced forgetting has also been found in recognition tests (Hicks and Starns, 2004; Verde, 2004; Gómez-Ariza et al., 2005; Spitzer and Bäuml, in press). As outlined in section 2.13.1.2, recognition can be based on recollective processes and/or familiarity processes (Tulving, 1985; Jacoby, 1991). In retrieval-induced forgetting, the recognition tests provided evidence that retrieval practice affects both recollective and familiarity processes of the unpracticed material. Studies in which associative recognition was employed reported a reduction in recollective processes (Verde, 2004); studies in which item recognition was employed reported additional reductions in familiarity processes (Spitzer and Bäuml, in press). Regarding implicit memory tests, a mixed picture arises. Whereas some studies found reliable impairment in implicit tests (Veling and van Knippenberg, 2004), others failed to find an effect (Racsmany and Conway, 2006). Still others found effects in some tests but no effects in others (Perfect et al., 2002; see also Camp et al., 2005).

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

Two further lines of research support this view of retrieval-induced forgetting. First, response latency analysis sheds light on the dynamics of recall, allowing conclusions on the size of the underlying search set and the memory strength of the set's items (for a review, see Wixted and Rohrer, 1994). Applying such response latency analysis, Bäuml et al. (2005) found that retrieval practice reduces unpracticed items' recall probability but does not affect their response latency. This result mirrors typical effects of item strength manipulations as they occur as a result of variations in study time or study trials (Rohrer, 1996; Wixted et al., 1997), indicating that retrieval practice affects the memory strength of unpracticed items but does not prevent the items from being sampled. Second, a recent electrophysiological study reported retrieval-specific brain activities during the retrieval-practice phase, which were reflected in sustained prefrontal event-related potentials and correlated with the amount of forgetting in the later memory test (Johansson et al., 2007). The reported retrieval-specific effect indicates that retrieval-induced forgetting is the result of processes operating during retrieval practice and is not the result of blocking at test.

The inhibitory view of retrieval-induced forgetting presupposes some degree of retrieval competition and relational processing between single items. Consistently, Smith and Hunt (2000) reported reliable retrieval-induced forgetting if individuals encoded items in a relational way but not when they encoded them in an item-specific way, that is, by their features and distinctive qualities (regarding relational and item-specific processing, see Hunt and McDaniel, 1993). It is often assumed that positive moods encourage relational processing and negative moods encourage item-specific processing (e.g., Storbeck and Clore, 2005), thus raising the expectation that mood affects retrieval-induced forgetting. Bäuml and Kuhbandner (2007) examined the effect of positive and negative mood induction immediately before retrieval practice on retrieval-induced forgetting. Indeed, negative mood induction, but not positive mood induction, eliminated the forgetting.

Once material is processed in a relational way so that retrieval competition arises, the forgetting may be affected by the degree of interitem associations between the practiced and unpracticed material. Indeed, both instructions to interrelate to-be-practiced and not-to-be-practiced items in a meaningful way (Anderson et al., 2000b) and the use of strong pre-experimental associations between the two types of items (Bäuml and Hartinger, 2002; Bäuml and Kuhbandner, 2003) have been shown to eliminate retrieval-induced forgetting. Under conditions that simulate educational situations, Chan et al. (2006) even demonstrated that retrieval practice can benefit memory for the unpracticed material. These findings are consistent with a variant of item suppression in which items are represented as sets of features, and features that the unpracticed item shares with the practiced items are strengthened rather than inhibited. Because of this strengthening of some of the item's features, forgetting is reduced or eliminated and may even be reversed to show recall facilitation (for details, see Anderson, 2003).

At the core of the retrieval-practice paradigm is the action of an inhibitory mechanism that directly affects the representation of the irrelevant material. This effect is observable across a wide range of memory tests because the items' representation itself is affected. Note, however, that because item suppression induces a difference in relative strength between practiced and unpracticed items, the inhibitory process should also create a competition bias at test, favoring early recall of practiced items at the expense of unpracticed items. Moreover, because there is not only suppression of unpracticed material but also strengthening of the practiced material, this bias should be particularly strong, triggering additional blocking in free-recall tasks. Results from several studies are consistent with this prediction (e.g., Anderson et al., 1994).

2.13.2.2.2 Output interference

If retrieval of material can cause forgetting of nonretrieved material, then retrieval-induced forgetting should also occur in the course of a recall test. In principle, recall of a first item should cause inhibition of the still-to-be-remembered items, as should recall of the second item, the third item, and so on. As a result, recall performance at test should decline as a function of testing position. This pattern is exactly what has been known as output interference for more than 30 years. Output interference has been demonstrated in a number of studies (Smith, 1971; Roediger, 1974; Roediger and Schmidt, 1980) and, among other factors, was taken as evidence that recall is a self-limiting process (Roediger, 1978).

Originally, output interference was explained in terms of retrieval competition, assuming that recall of a first item strengthens the item and thus, because of biased retrieval competition, makes retrieval of the remaining items harder. This blocking account obviously disagrees with the explanation of retrieval-induced forgetting as it occurs in the retrieval-practice paradigm (see section 2.13.2.2.1). Arguably, however, retrieval-induced forgetting as studied in the retrieval-practice paradigm and retrieval-induced forgetting as studied in the output-interference paradigm should be mediated by similar mechanisms and might even be equivalent.

A blocking account of output interference predicts that the forgetting should disappear once item-specific probes are presented at test. Thus, recall should not decline with testing position if, for instance, the items' unique initial letters were provided as cues (see section 2.13.2.1.1). In contrast, if output interference was mediated by the same mechanism as the forgetting in the retrieval-practice paradigm, recall should decline with testing position regardless of whether item-specific cues were provided or not (see section 2.13.2.2.1). As it turned out, output interference effects are maintained in the presence of item-specific probes (Anderson et al., 1994; Anderson and Spellman, 1995; Bäuml, 1997), which supports the suggested equivalence of effects in the two paradigms.

The relation between the two paradigms was further examined in two studies in which the role of item strength and item similarity in output interference were examined (Bäuml, 1998; Bäuml and Hartinger, 2002). The two studies found effects of item strength and item similarity in output interference that mirrored those known from the retrieval-practice paradigm, which is consistent with the view that the same inhibitory mechanisms operate in the two paradigms. Given the evidence for item suppression in studies using the retrieval-practice paradigm (see section 2.13.2.2.1), these results suggest a role of item suppression in output interference as well.

2.13.2.2.3 Summary

Like relearning of relevant material, retrieval of relevant material can impair memory for irrelevant material. Results from the retrieval-practice paradigm suggest that retrieval triggers two processes: one process strengthening the practiced material and a second process inducing inhibition of the unpracticed material. These two processes create some difference in relative strength between practiced and unpracticed items and thus leave room for blocking. Going beyond blocking, however, retrieval affects the unpracticed material's representation itself. Such item suppression is at the core of retrieval-induced forgetting and implies that the inaccessibility of the irrelevant material is not restricted to free-recall tasks but generalizes to a wide range of memory tests. The results also indicate that the detrimental effects of retrieval and relearning are mediated by different mechanisms.

2.13.2.3 Directed Forgetting

Relearning and retrieval practice may be regarded as forms of memory updating, in which part of previously studied material is reexposed or retrieved, suggesting that it is more relevant than the remaining material (Anderson and Schooler, 1991). Inhibitory processes then act on the seemingly less relevant material, either by blocking its access during recall or by directly affecting the material's representation itself. A different form of updating may arise in situations in which new information, such as the new computer password, has to displace old information, for example, the expired password. In this case, memory for the new relevant information would benefit if memory for the irrelevant out-of-date information was reduced. Whether such updating is part of our memory and is mediated by inhibitory processes has been studied in list-method directed forgetting.

2.13.2.3.1 List-method directed forgetting

In list-method directed forgetting, participants learn two lists of items. After learning List 1, they receive a cue to either forget or continue remembering this list before studying List 2. After learning List 2, a recall or recognition test is conducted in which participants are asked to remember the previously studied items, including those the participants were originally cued to forget. Memory for List 1 and List 2 items is then compared between the two conditions (Bjork, 1970, 1989; **Figure 4**).

The results from numerous recall experiments show two effects of the forget cue: reduced recall of List 1 items, referred to as forgetting and improved recall of List 2 items, referred to as enhancement (for a review, see MacLeod, 1998). These effects provide the first evidence for memory updating in this paradigm, demonstrating reduced accessibility for the out-of-date information and enhanced accessibility for the new information. Arguably, the forgetting of List 1 items might be a result of demand characteristics, because participants may not try as hard to recover the to-be-forgotten List 1 items as they do for the to-be-remembered List 2 items. The effect of the forget cue, however, does not disappear if money is offered for recalled List 1 items (MacLeod, 1999), indicating that the effect probably is not a result of demand characteristics (for a recent variant of list-method directed forgetting, see Szpunar et al., in press).

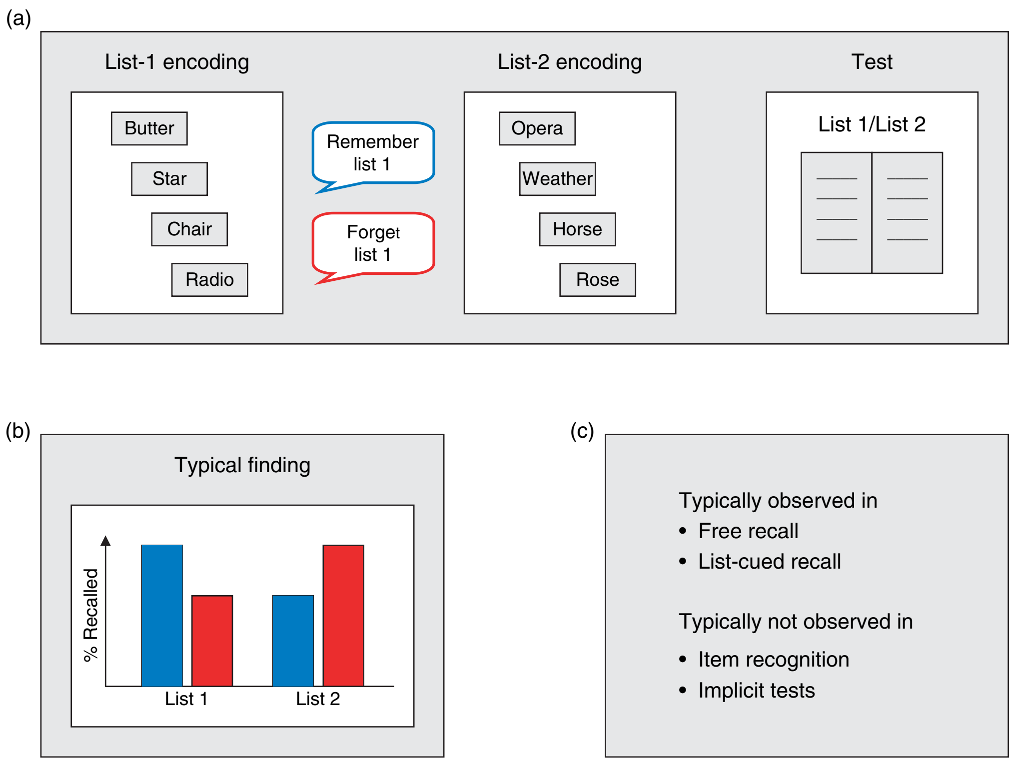

Figure 4 List-method directed forgetting. (a) The experimental paradigm. Participants study two lists of items and, after the presentation of List 1, receive a cue to either forget or continue remembering this list before studying List 2. After study of List 2, a recall test is conducted in which participants are asked to recall all of the previously presented items, including those the participants were originally cued to forget. (b) The typical finding. Compared with remember-cued participants, forget-cued participants typically show impaired recall of List 1 items and improved recall of List 2 items, referred to as the forgetting and the enhancement induced by the forget cue. (c) Memory tests. Examples of memory tests in which list-method directed forgetting typically arises and in which it typically does not arise.

In free-recall tests, participants in the forget condition show a tendency to recall List 2 items before List 1 items (Geiselman et al., 1983). As a result, the effect of the forget cue on List 1 items could be a result of blocking and output interference, in which early recall of List 2 items impairs subsequent recall of List 1 items. The two effects of the forget cue, however, have been found regardless of whether the two lists were recalled simultaneously in any order the participants wished (i.e., with a tendency to recall List 2 items before List 1 items) or whether they were recalled successively with List 1 items recalled prior to List 2 items (Geiselman et al., 1983; Zellner and Bäuml, 2006). This result indicates that list-method directed forgetting does not reflect effects of blocking and output interference.

List-method directed forgetting has also been assessed by means of recognition tests. In most of these studies, no effect of the forget cue emerged for either List 1 items or List 2 items (Geiselman et al., 1983; Basden et al., 1993; Sego et al., 2006; for an exception, see Benjamin, 2006). Impairments on List 1 recognition, however, were found when participants were required to make source memory judgments (Geiselman et al., 1983). On the basis of the recollection/familiarity distinction, this finding suggests that the forgetting in this paradigm reflects primarily a deficit in recollection and not in familiarity. No effects of the forget cue arose in implicit memory tasks (Basden et al. 1993; Basden and Basden, 1996).

Two particularly prominent accounts of list-method directed forgetting are selective rehearsal and inhibition. The selective rehearsal account assumes that during List 2 encoding participants in the remember condition rehearse both List 2 and List 1 items, whereas in the forget condition, the forget cue leads to selective rehearsal activities on List 2 items, thus improving later recall of List 2 at the expense of List 1 (Bjork, 1972). The inhibition account assumes that, by inhibiting List 1 items, the forget cue deactivates retrieval routes to List 1 items and, because of the resulting decrease in the items' interference potential, simultaneously improves access to List 2 items (Geiselman et al., 1983). Because the selective rehearsal hypothesis attributes directed forgetting to differences in encoding, it predicts effects on recall and recognition tests. The inhibition account attributes directed forgetting to effects on the List 1 items' retrieval routes, and thus the forgetting should be present in recall but should be absent in recognition. The above-mentioned failure to find directed forgetting on recognition tests supports the inhibition account.

Further evidence for the inhibition view arises from an experiment by Geiselman et al. (1983). They used a variant of the standard paradigm, in which participants alternately learned items intentionally and incidentally. Indeed, all participants were told to learn one item and judge the pleasantness of the next one. For both learn and judge items, the standard pattern of directed forgetting arose with reduced recall of List 1 items and improved recall of List 2 items. This result challenges the selective rehearsal hypothesis, because participants in the remember condition should not have tried to rehearse the incidental List 1 items and, rather, should have focused their rehearsal on the learn items. Incidental List 1 items thus should have shown the same performance in the remember as in the forget condition, which was not the case.

For most of the paradigms discussed in this chapter, there is broad consensus that inhibition operates on an item level. In contrast, in list-method directed forgetting it has been suggested that the inhibition operates on a list-level basis. According to this view, List 1 items form a unit, and the presence of the forget cue induces inhibition of the whole unit. Evidence in favor of this view comes from the Geiselman et al. (1983) observation that incidentally learned List 1 items share the same fate as intentionally learned List 1 items. Further support for the view arises from part-list reexposure studies. In these studies, after learning of the two lists, a subset of the List 1 items was reexposed as part of a recognition test before all previously studied items were to be recalled on a final recall test. The results provided evidence that part-list reexposure eliminates the forgetting of the remaining items (Bjork et al. 1973; Goernert and Larson, 1994; Bjork and Bjork, 1996), which is consistent with the view that the inhibition operates on a list-level basis. More recently, however, the findings were challenged by results suggesting that part-list reexposure reinstates mainly reexposed items and not the entire List 1 episode (Basden et al., 2003).

A priori, one might like to assume that the presence of the forget cue in the list-method directed forgetting procedure is sufficient to create the forgetting of List 1 items. As the results from two lines of research show, however, this is not the case. First, it has been found that the presentation of the forget cue creates forgetting only if it is presented before List 2 encoding, but not if it is presented after the encoding (Bjork, 1970). Second, the effect of the forget cue arises only if there is additional List 2 encoding. That is, the forgetting of List 1 items disappeared if the forget cue was provided, but no additional List 2 learning took place (Gelfand and Bjork, 1985; Pastötler and Bäuml, in press). This finding indicates that the presence of the forget cue per se is not sufficient to create list-method directed forgetting. In particular, the result suggests that the inhibitory mechanism in this paradigm operates during List 2 encoding.

Accounts of directed forgetting are typically one-mechanism accounts according to which the same mechanism underlies the two effects of forgetting and enhancement. Although enhancement and forgetting in directed forgetting often go hand in hand, recently some exceptions to this rule have been observed, and forgetting has been found without enhancement (Conway et al., 2000; Sahakyan and Delaney, 2003, 2005; Zellner and Bäuml, 2006), and enhancement obtained without forgetting (Macrae et al., 1997; Benjamin, 2006). These dissociations suggest the action of two separate mechanisms, one mediating the forgetting and the other mediating the enhancement. Consequently, a two-mechanism account was suggested, according to which the forgetting is caused by some form of inhibition, whereas the enhancement results from a change in people's List 2 encoding with more elaborate encoding in the forget than in the remember condition (Sahakyan and Delaney, 2003).

At the core of list-method directed forgetting is the action of an inhibitory mechanism that induces effects on the irrelevant material by affecting the items' retrieval routes to their cue. Such inhibition should also trigger blocking. The difference in retrieval strength between inhibited List 1 items and noninhibited List 2 items should create biased retrieval competition, with relevant items being recalled prior to irrelevant items. Although there is evidence for the predicted recall order (Geiselman et al., 1983), to date such blocking effects have not been uncovered (Geiselman et al., 1983; Zellner and Bäuml, 2006).

2.13.2.3.2 Item-method directed forgetting

In list-method directed forgetting, relevant new material is encoded after irrelevant old information, initiating updating processes on the out-of-date information. However, relevant and irrelevant material may also be presented interspersed. In this case, different processing of the two types of information might be achieved by triggering inhibitory processes on each single irrelevant item. Whether such processes can affect later accessibility of the irrelevant information has been studied in item-method directed forgetting.

In item-method directed forgetting, participants study a list of items in which a cue to remember or forget the item follows presentation of each single item. Later, a memory test is conducted in which both to-be-remembered (TBR) and to-be-forgotten (TBF) items have to be recalled or recognized (Woodward and Bjork, 1971; see **Figure 2(a)** for a formally related paradigm). Performance for the relevant and irrelevant material is directly compared without reference to any additional baseline conditions (for a review, see MacLeod, 1998). Results from free-recall experiments typically reveal a difference in performance between TBR and TBF items, with better recall for TBR than TBF items, thus showing that the cuing is effective (Davis and Okada, 1971; Woodward and Bjork, 1971; Basden et al., 1993). Moreover, as is true in list-method directed forgetting, the effect is probably not a result of demand characteristics, because it does not disappear if money is offered for recall of the TBF items (MacLeod, 1999).

List-method directed forgetting is present in recall but is absent on recognition tests. In contrast, the difference between TBR and TBF items in item-method directed forgetting has been observed in both recall and recognition tests (Davis and Okada, 1971; MacLeod, 1989; Basden et al., 1993). Regarding the contribution of recollection and familiarity on recognition performance, the effect of the forget cue seems to reflect a difference in recollective processes rather than in familiarity. This is indicated because the difference in performance has been found to be present in remember judgments but not in know judgments (Gardiner et al., 1994; Basden and Basden, 1996). A different performance for TBR and TBF items was also found in implicit memory tasks (MacLeod, 1989; Basden and Basden, 1996), although the effect does not seem to be present in all types of tasks (MacLeod and Daniels, 2000).

The simplest view of these findings is a strengthening view according to which TBF and TBR items only differ in the degree to which the single items are rehearsed and strengthened in response to the respective cue (Bjork, 1972; Basden et al., 1993; see also MacLeod, 1998). Such an interpretation is consistent with the finding of differences between TBR and TBF items in most types of memory tests, including recognition and some implicit memory tasks. Following this view, the forget cue would not inhibit retrieval routes or the memory representation of the TBF items. Because of the induced difference in relative strength between the two types of items, the forget cue, however, might create some blocking at test, with early recall of (stronger) TBR items blocking access to the (weaker) TBF items. If true, item-method directed forgetting would be similar in character to what occurs in the list-strength effect (see section 2.13.2.1.1). Moreover, item-method directed forgetting would reflect an instructional variant of the list-strength effect.

Our knowledge of the role of inhibitory processes in the list-strength effect is largely based on comparisons between performance in the mixed-list condition and performance in two pure-list conditions that are used as baseline conditions (see section 2.13.2.1.1). Item-method directed forgetting may also create a form of mixed list, consisting partly of the stronger TBR items and partly of the weaker TBF items. In this case, however, performance is typically not compared with pure-list baseline conditions. Such comparisons would strongly improve the database to derive a more clearcut indication of the role of inhibitory processes in item-method directed forgetting. Until then, it seems that inhibition may play a role in item-method directed forgetting experiments, but that this effect is restricted to blocking and is not caused by direct effects on the items' retrieval routes or the items' memory representation.

2.13.2.3.3 Summary

The presence of a forget cue can induce forgetting of irrelevant material. Depending on whether the relevant material is presented subsequent to the irrelevant material (the list method) or relevant and irrelevant material are presented interspersed (the item method), different effects arise. In list-method directed forgetting, the effect of the forget cue is found in free-, and list-cued recall tests but not in recognition or implicit memory tasks. The effect is likely to be the result of some deactivation of the retrieval route between the TBF items and their cue. The representation of the TBF items itself, however, does not seem to be affected. In item-method directed forgetting, the effect of the forget cue can be found across a wide range of memory tests, including free recall and recognition tasks. The results are largely consistent with a strengthening view, according to which the two cues lead to items of different memory strength because of selective rehearsal. While this difference in relative strength may create blocking in recall tests, no clearcut evidence for other forms of inhibitory processes, such as direct effects on retrieval routes or item representations, has yet been identified. It thus seems that quite different mechanisms are at work in list-method and item-method directed forgetting.

2.13.2.4 Think/No-Think Impairment

In item-method directed forgetting, a forget cue is provided after presentation of an item to inform participants that the item is irrelevant and will not be tested later. As summarized in the previous section, the results from a number of studies have shown that, in response to such a cue, rehearsal of an item can be stopped, thus demonstrating that forget cues at encoding can be effective. The question arises of whether a forget cue can not only stop rehearsal but may stop retrieval as well (Weiner and Reed, 1969). Evidence for this type of proposal arises from studies using the think/no-think paradigm.

The think/no-think paradigm is a memory adaptation of the go/no-go task, which is typically used to study control of prepotent motor responses. In the think/no-think paradigm, participants study weakly related word pairs (e.g., butter-opera) and are trained to answer with the appropriate associate (target) upon presentation of its counterpart (cue). After the training, participants engage in a think/no-think task. In each trial of the task, the cue word (butter) is provided and participants are required either to remember (think) or to actively suppress any thought (no-think) about its corresponding target (opera) and not let it enter consciousness. A large number of such trials is typically conducted. In a final cued-recall test, participants are then asked to recall the targets in response to the original stimulus cue, regardless of whether in the intermediate phase they were instructed to think about the item or to suppress it. As a variant of this testing procedure, a semantically related word (music) may be presented as cue rather than the original stimulus cue, thus permitting a test of cue-independent forgetting in this paradigm (Anderson and Green, 2001; **Figure 5**).

Results from several studies showed improved recall of think items and impaired recall of no-think items relative to baseline items, which were neither remembered nor suppressed in the intermediate think/no-think phase (Anderson and Green, 2001;

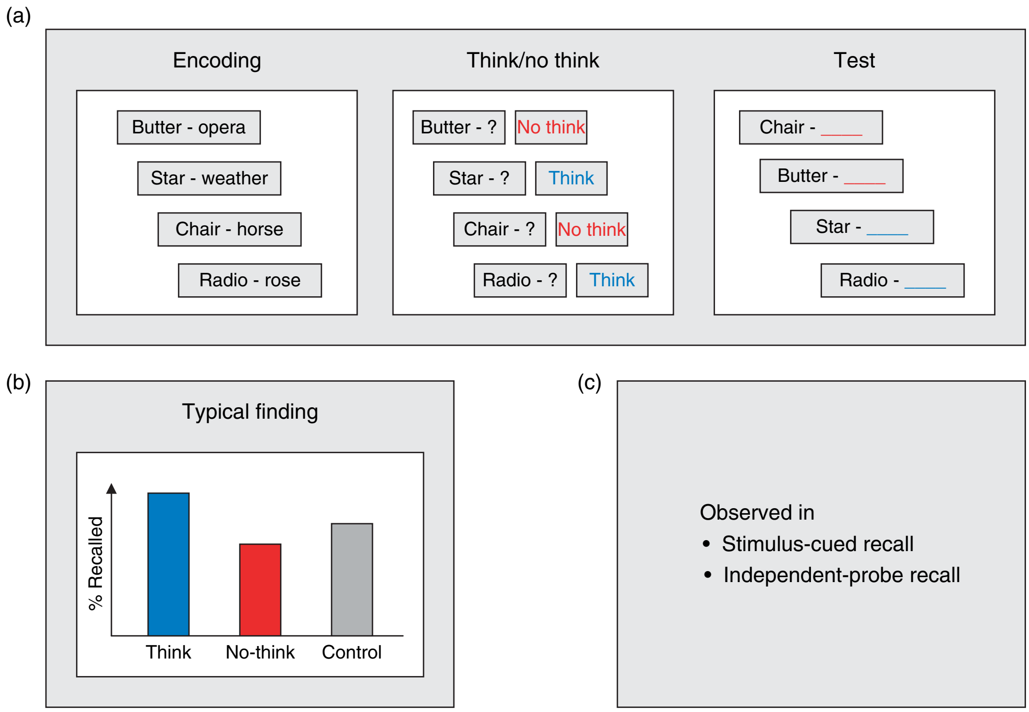

Figure 5 Think/no-think impairment. (a) The experimental paradigm. Participants study weakly related cue–target pairs and are trained to answer with the target upon presentation of its cue. After the training, participants engage in the think/no-think task. In each trial of the task, they are provided with a cue word and are required to either remember (think) or actively suppress any thought (no-think) about its corresponding target. On a later test, all targets are tested given their associate as the retrieval cue. (b) The typical finding. Think items are recalled better and no-think items are recalled worse than control items, which were neither remembered nor suppressed in the intermediate think/no-think task. (c) Memory tests: Examples of memory tests in which think/no-think impairment has been observed.

Anderson et al., 2004; Hertel and Calcaterra, 2005; Depue et al., 2006). In particular, the effect did not only arise if at test the original stimulus cue was presented, but was also present if a semantically related independent probe was provided (Anderson and Green, 2001; Anderson et al., 2004). Again, the effect does not seem to be a result of demand characteristics, as the forgetting has been found to be still present if money was offered as a reward for each recalled no-think item (Anderson and Green, 2001).

The few studies that to date reported successful forgetting in the think/no-think paradigm indicate that the forgetting in this paradigm arises if the number of no-think trials is high (16 trials) but is not present if the number of such trials is relatively low (one or four trials). Moreover, even with a high number of no-think trials, the effects are typically small, although the forgetting can increase somewhat if emotional material rather than neutral material is employed in the experiment (Depue et al., 2006). Researchers also failed to replicate the finding, despite several careful attempts to do so (Bulevich et al., in press), which suggests that the forgetting in this paradigm may not be very reliable.

Anderson and Green (2001) argued that the forgetting in the think/no-think paradigm is caused by inhibition. According to this account, during no-think trials, the memory representation of the targets is reduced so that accessibility is lowered regardless of which cue is provided and which retrieval route is used. In consequence, the forgetting should be observed across a wide range of memory tests, including independent-probe tasks, recognition tasks, or implicit memory tasks. Although there is evidence for cue independence in this paradigm (Anderson and Green, 2001; Anderson et al., 2004; but see Bulevich et al., in press, for failures to get the effect), no studies have yet been reported examining think/no-think impairment in recognition or implicit memory tests. Using imaging techniques, Anderson et al. (2004) examined neural correlates of the forgetting during no-think trials. They identified an interaction between prefrontal cortex and hippocampus, which was related to the forgetting of no-think items on the final recall test and was interpreted as evidence for inhibition. However, because there was also increased activity in other brain regions during no-think trials, it was argued that the forgetting might also be a result of subjects' attempts to think about something else rather than to inhibition (Hayne et al., 2006).

Indeed, rather than reflecting item suppression, the forgetting in this paradigm might also be caused by some form of inaccessibility created through associative interference. This might occur if, for instance, participants adopt a strategy of thinking about other, distracting words during no-think trials, thereby building new associations to the cue and increasing (retroactive) interference (Hertel and Calcaterra, 2005; Bulevich et al., in press). Because interference effects are typically restricted to situations in which the original cue is provided at test, such noninhibitory accounts of the phenomenon would not predict forgetting when independent probes are provided. The reported failure to find forgetting when independent probes are provided as cues (Bulevich et al., in press) thus supports the associative interference account of the phenomenon. In contrast, Anderson and colleagues' reports of cue independence (Anderson and Green, 2001; Anderson et al., 2004) challenge the interference account and support the suppression account. Obviously, further research is warranted.

The results from the think/no-think paradigm suggest that cues to stop retrieval of an item can cause later forgetting of the item. Item-method directed forgetting shows that cues to stop rehearsal of an item can also be effective. While these lines of evidence converge on the view that cues to stop the processing of items, be it at encoding or retrieval, can be successful, there is evidence that the two forms of stopping are nonetheless different. First, stopping rehearsal seems to be relatively easy for participants, typically inducing strong performance differences between TBR and TBF items. In contrast, stopping retrieval seems to be hard, and participants may even fail to show forgetting in this task. Second, the stopping of rehearsal does not seem to be inhibitory in the sense that a TBF item is inhibited in its representation or its retrieval routes. In contrast, the stopping of retrieval has been argued to induce deactivation of the item representation, so that the item becomes unavailable. If true, stopping rehearsal and stopping retrieval may be quite different things in memory.

2.13.2.5 Part-List Cuing Impairment

What is common to the paradigms described earlier (in the subsections in 2.13.2 to this point) is that inhibitory mechanisms operate to emphasize accessibility of relevant material at the expense of that for irrelevant information. Inhibition thus seems to serve an adaptive goal and to support memory to function efficiently. On the other hand, there is evidence that inhibition is not always adaptive and goal directed. This is indicated by an example from the memory literature in which inhibitory processes emphasize accessibility of irrelevant material at the expense of that for relevant information. The example is part-list cuing impairment.

2.13.2.5.1 Beneficial and detrimental effects of cuing

There is broad agreement in the literature that the presence of adequate retrieval cues is crucial for successful episodic memory (e.g., Tulving, 1974). Consistently, cuing has been found to facilitate recall in many situations. For instance, if a categorized list with several items from each category is presented to participants and, at test, the category names or one item from each category are provided as retrieval cues, then such cuing typically enhances recall compared to unaided free recall (Tulving and Pearlstone, 1966; Tulving and Psotka, 1971).

Cuing, however, is not always facilitatory and can even be detrimental. If participants learn a categorized list and, at test, receive several items from each category as retrieval cues, then such part-list cuing often reduces recall performance for the remaining items, compared with the condition in which just one category exemplar is provided as a retrieval cue (Slamecka, 1968; Roediger, 1973; for reviews, see Nickerson, 1984, or Roediger and Neely, 1982). In general, if more part-list cues are provided than necessary to remind participants of the various categories, or subjective units, cuing can be detrimental (Basden and Basden, 1995).

Prior work assumed that part-list cuing impairment is caused by blocking (Roediger, 1973; Rundus, 1973). The idea was that reexposure of items as cues strengthens these items' representation. During attempts to recall the noncue items at test, this strengthening of the cue items then should lead participants to covertly retrieve cue items before noncue items and thus block recall of the noncues. Part-list cuing, therefore, should mimic the effects of relearning, in which reexposure has been shown to block recall of the target material (see section 2.13.2.1.2).

Prior work demonstrated that the detrimental effects of relearning disappear once item-specific probes, such as the targets' unique initial letters, are provided to aid recall of the items. Thus, if part-list cuing impairment, like the detrimental effects of relearning, was caused by blocking, then part-list cuing impairment should also be absent if item-specific probes were provided. The issue was directly addressed in an experiment by Bäuml and Aslan (2004). Participants learned category exemplars consisting of target and nontarget items. In a subsequent phase, the nontarget items were reexposed, either for relearning (i.e., for a second study trial) or for use as retrieval cues at test. This reexposure occurred immediately before test, mimicking the typical part-list cuing procedure, or separated from test by a distractor task, mimicking typical part-list relearning. At test, the category-plus-first-letter cues of the target items were presented, and participants were instructed to recall the target items.

As expected from the relearning literature, part-list relearning had no detrimental effect on the target material. In contrast, part-list cuing had a detrimental effect. This held true both when the reexposure occurred immediately before test and when reexposure was separated from test by a distractor task. This finding indicates that part-list cuing differs from relearning and that its detrimental effects are not caused by blocking. In particular, it shows that part-list cuing impairment reflects an instructional effect. Reexposure induces forgetting when participants are oriented to use the reexposed items as retrieval cues (part-list cuing) but does not induce forgetting when the reexposed items are presented for an additional study trial (part-list relearning).

Results from recognition studies support the view that part-list cuing differs from relearning and other strengthening effects. Indeed, while strength-induced forgetting is typically absent in recognition tests, reliable part-list cuing impairment was found when memory for the noncues was assessed by means of a recognition task (Todres and Watkins, 1981). Part-list cuing impairment also arose in speeded recognition (Neely et al., 1983; Oswald et al., 2006). Because recognition performance is assumed to rely more on familiarity than recollection when participants are required to make recognition decisions very quickly (e.g., Yonelinas, 2002), this finding suggests that part-list cuing does not only affect recollective processes but affects the familiarity of the noncue items as well.

There is evidence that part-list cuing impairment is also present in recall tasks that employ independent probes (see section 2.13.2.6.1). Aslan et al. (2007a) reported a repeated-testing experiment in which, in the first test, participants were provided with part-list cues and were asked to recall half of the target items when cued by the items' unique initial letters. After a delay, a second test was conducted in which no part-list cues were provided and participants were asked to recall the remaining targets by means of independent probes, that is, probes that were not used in a previous phase of the experiment. Part-list cuing impairment was present in both tests, indicating that independent probes do not eliminate the forgetting.

The results from all these studies are consistent with an inhibitory view of part-list cuing impairment according to which part-list cuing triggers inhibitory processes that directly affect the item representation of the noncues. In this sense, the effect may mimic the effect of retrieval practice in retrieval-induced forgetting (see section 2.13.2.2). Indeed, several studies compared the detrimental effects of retrieval practice and part-list cuing directly within a single experiment (Bäuml and Kuhbandner, 2003; Bäuml and Aslan, 2004; Zellner and Bäuml, 2005). In all these cases, the same qualitative and quantitative effects arose. These findings agree with the view that part-list cuing leads to instructed covert retrieval of cue items and causes inhibition of noncue items very similar to how overt retrieval in retrieval-induced forgetting inhibits nonretrieved items (Bäuml and Aslan, 2004).

Retrieval-induced forgetting has been shown to be lasting and to still be present when item-specific probes are provided (see section 2.13.2.6.1). Consistent with the inhibitory view of part-list cuing impairment, part-list cuing impairment can also persist, even with item-specific probes (Bäuml et al., 2002; Bäuml and Aslan, 2004, 2006). On the other hand, there are demonstrations that, under certain conditions, the cuing effect can disappear with a delay (Basden and Basden, 1995; Bäuml and Aslan, 2006) and can be absent in the presence of item-specific probes (Aslan and Bäuml, in press). Bäuml and Aslan (2006) identified associative relations at encoding as a crucial factor in part-list cuing impairment. Data suggest that the detrimental effect of part-list cues is mediated by inhibition in situations with a relatively low level of interitem associations and is mediated by noninhibitory mechanisms in situations with a relatively high level of interitem associations. Thus, apparently more than one mechanism is involved in this form of forgetting.

2.13.2.5.2 Summary

Providing a subset of studied material as retrieval cues for recall of the remainder often does not enhance but rather reduces accessibility of relevant targets. Such part-list cuing impairment reflects an instructional effect, with reexposure of items being detrimental only if participants are oriented to use the items as retrieval cues. Part-list cuing differs from part-list relearning and, in many situations, is the result of the action of an inhibitory mechanism that affects the noncue items' representation directly. Part-list cuing impairment thus mirrors retrieval-induced forgetting, in which retrieval practice affects the representation of the nonretrieved items. In contrast to retrieval-induced forgetting, however, part-list cuing is not adaptive or goal directed but, rather, provides an example in which inhibitory processes can impair access to relevant information rather than enhance it.

2.13.2.6 Developmental Trajectory of Inhibitory Processes

The role of inhibition in cognition is of central importance in the literature on cognitive development. This stems in part from findings reporting poor performance of young children and older adults in a number of inhibition tasks (Simpson and Foster, 1986; Tipper et al., 1989; Hartman and Hasher, 1991; Hasher et al., 1997). In particular, it is attributable to the hypothesis that young children and older adults suffer from a general deficit in inhibitory function (Hasher and Zacks, 1988; Bjorklund and Harnishfeger, 1990). Such a general deficit in inhibitory function might also apply to memory and be at the heart of the reduced memory performance of young children and older adults. It thus is important to examine the performance of young children and older adults in the inhibitory paradigms addressed earlier (in the subsections in 2.13.2 to this point).

The hypothesis of a general inhibitory deficit in young children and older adults indicates that the two age groups show problems across the whole range of inhibitory paradigms reviewed above. This holds while the results reported in the subsections in 2.13.2 to this point suggest the action of quite different inhibitory mechanisms in the different paradigms. Knowledge on the developmental trajectory in the single paradigms would improve our understanding of memory development and would also improve our understanding of the development of cognitive inhibition in general. In recent years, a number of results emerged regarding young children's and older adults' retrieval-induced forgetting, directed forgetting, and part-list cuing impairment. These results are reviewed in the next sections.

2.13.2.6.1 Retrieval-induced forgetting

In children, retrieval-induced forgetting has been studied using both cued recall and recognition tasks at test. Zellner and Bäuml (2005) reported two experiments using verbal categorized lists and category-cued recall tasks at test. First graders, second graders, fourth graders, and young adults were tested. All four groups of participants showed the standard pattern of retrieval-induced forgetting with improved recall of practiced items and impaired recall of unpracticed items. In particular, there were no differences in the amount of forgetting across participant groups, suggesting that the inhibition was effective in young children (**Figure 6(a)**).

Using pictorial material, Ford et al. (2004) examined retrieval-induced forgetting in 7-year-olds by means of a yes/no recognition task in the practice phase and a category-cued recall test and a recognition test in the final test phase. In both cases, robust retrieval-induced forgetting was found. Furthermore, the magnitude of the effect did not differ between children and young adults. Analogous results were reported by Lechuga et al. (2006), who examined retrieval-induced forgetting in 8- and 12-year-old children. Related results were obtained in studies using the selective postevent review (questioning) procedure with 5- and 9-year-olds (Conroy and Salmon, 2005) and 5- to 6-year-olds (Williams et al., 2002). Review of some events impaired memory for nonreviewed events with comparable impairment in all age groups.

Only very few studies exist to date in which retrieval-induced forgetting was studied in older adults. In a nondevelopmental study, Moulin et al. (2002) found retrieval-induced forgetting in Alzheimer disease patients and healthy age-matched older adults in both a standard category-cued recall and a category generation task. While this study demonstrated reliable forgetting in older adults, it left open the question of whether the effect differs quantitatively from that in younger adults. Aslan et al. (2007b) examined retrieval-induced forgetting in younger and older adults and found equivalent amounts of

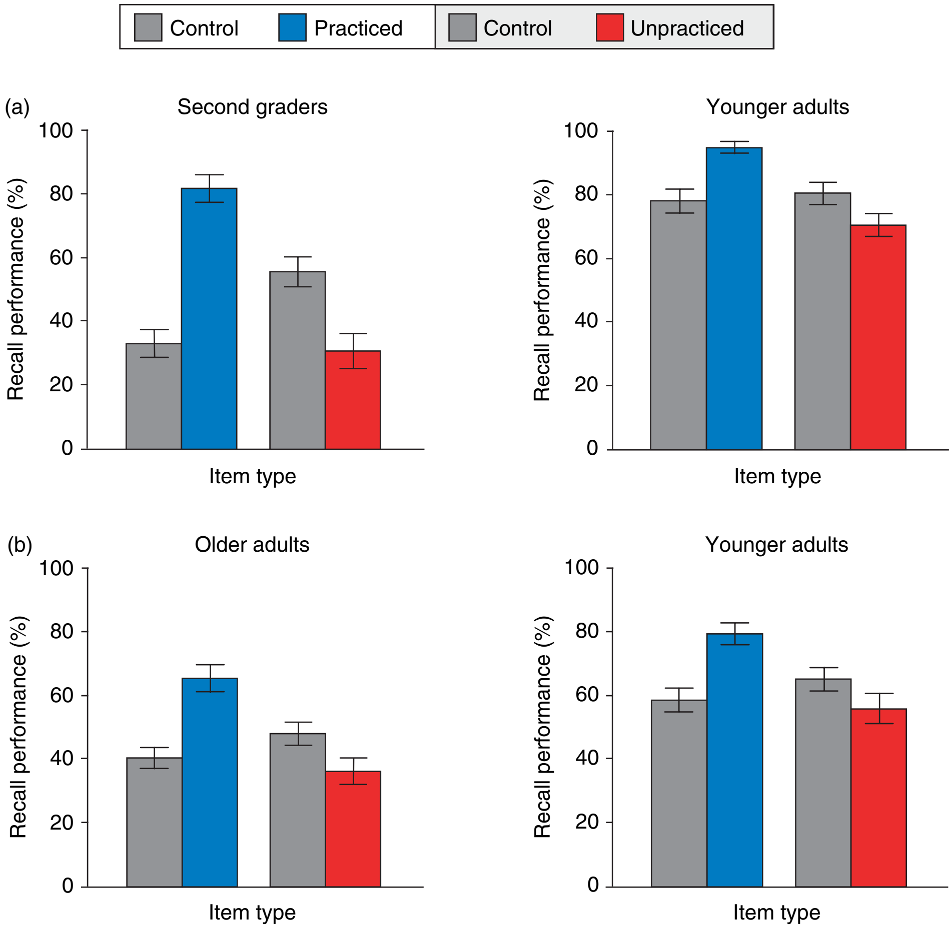

Figure 6 Retrieval-induced forgetting in young children and older adults. (a) Recall percentage (and standard error) of retrieval-practiced and not-retrieval-practiced items and of their (separate) control items in second graders and younger adults. For both participant groups, the data show beneficial effects of retrieval practice on practiced items and detrimental effects of retrieval practice on unpracticed items. From Zellner M and Bäuml K-H (2005) Intact retrieval inhibition in children's episodic recall. *Mem. Cogn.* 33: 396–404. Psychonomic Society, Inc., Experiment 1. Adapted with permission. (b) Recall percentage (and standard error) of retrieval-practiced and not-retrieval-practiced items and of their (separate) control items in younger and older adults. For both participant groups, the data show beneficial effects of retrieval practice on practiced items and detrimental effects of retrieval practice on unpracticed items. From Aslan A, Bäuml K-H, and Pastötter B (2007) No inhibitory deficit in older adults' episodic memory. *Psychol. Sci.* 18: 111–115. Blackwell Publishing, Experiment 1. Adapted with permission.

forgetting in the two age groups. This result held both when category names and when independent probes were provided as retrieval cues, suggesting that, in both age groups, the inhibition affects the items' memory representation itself (Figure 6(b)). Related results were again obtained when using the selective postevent review procedure (Koutstaal et al., 1999).

Thus, retrieval-induced forgetting seems to be present over most of the lifespan and to differ hardly, if at all, between young children, younger adults, and older adults. In particular, the results suggest that, in all these age groups, the effect is caused by the same inhibitory mechanism, which affects the nonretrieved items' representation itself. Thus, no evidence for an inhibitory deficit in young children or older adults arises in this type of task.

2.13.2.6.2 Directed forgetting

1. List-method directed forgetting

A number of studies examined list-method directed forgetting in young children (e.g., Bray et al., 1983; Harnishfeger and Pope, 1996). The results from these studies suggest that young children show problems in this type of task. In the study by Harnishfeger and Pope (1996), for instance, first, third, and fifth graders and young adults were compared. First and third graders failed to show directed forgetting and showed hardly any effect of the forget cue at all. Normal directed-forgetting performance, however, was present from fifth grade on. The inhibition mechanism apparently develops over the elementary school years (**Figure** 7(**a**)).

There are three published studies to date that have examined list-method directed forgetting in older adults. In the first study, Zacks et al. (1996) used a variant of the task in which several short lists had to be studied and recall performance was measured cumulatively after presentation of all lists. A greater amount of forgetting was found for younger than for older adults. The results, however, were affected by floor effects. In a second study, Sego et al. (2006) followed previous work by Geiselman et al. (1983) and let younger and older adults alternately learn items intentionally and incidentally. For both types of items, largely identical forgetting was found in the two age groups. Zellner and Bäuml (2006) compared younger and older adults' directed forgetting in three experiments, in which the forget cue was varied within and between participants, the two lists were unrelated or related to each other, and recall of the lists was required simultaneously or successively. No age-related difference in directed forgetting performance emerged in any of the three experiments (**Figure** 7(**b**)).

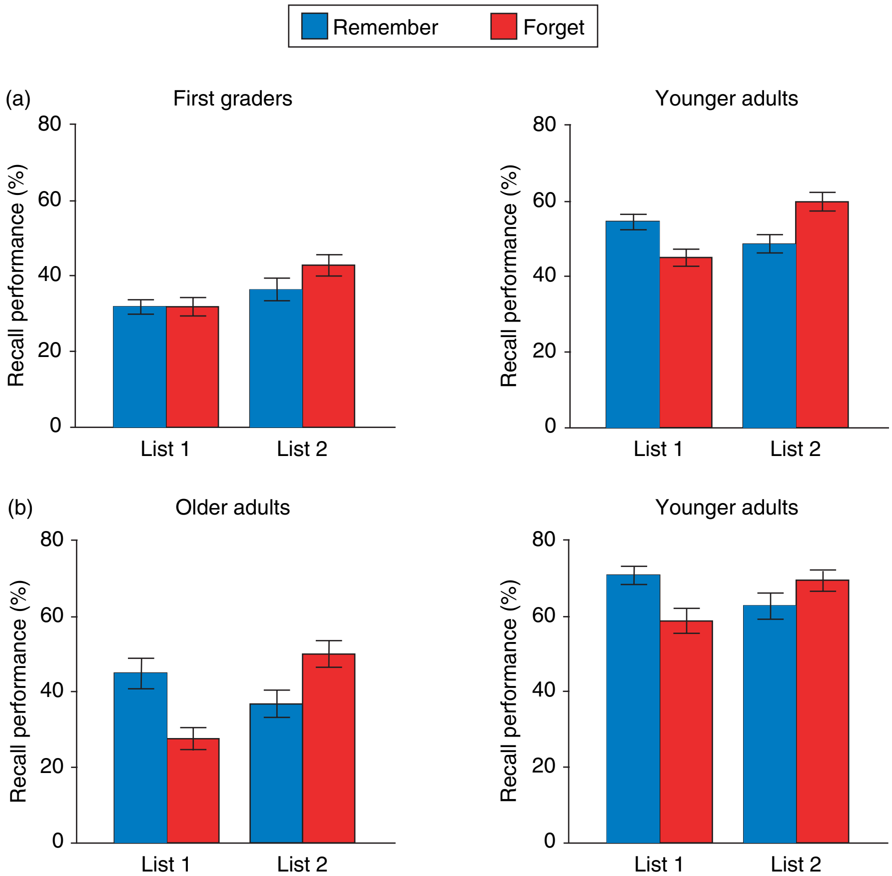

Figure 7 List-method directed forgetting in young children and older adults. (a) Recall percentage (and standard error) of List 1 and List 2 items as a function of whether a remember or forget cue was provided between learning of the two lists. While younger adults show the standard pattern of directed forgetting, for young children no reliable effect of the forget cue arises. This holds for both List 1 and List 2 items (K.-H. Bäuml, M. Zellner, and A. Aslan, unpublished data). (b) Recall percentage (and standard error) of List 1 and List 2 items as a function of whether a remember or forget cue was provided between learning of the two lists. Both younger adults and older adults show the standard pattern of List-method directed forgetting. From Zellner M and Bäuml K-H (2006) Inhibitory deficits in older adults – List-method directed forgetting revisited, *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 290–300, American Psychological Association, Experiment 3. Adapted with permission.

Thus, while young children fail to show list-method directed forgetting, older adults seem to show intact forgetting. This result suggests that the underlying inhibitory mechanism develops in later childhood. Once developed, however, it remains intact with increasing age. The inhibitory mechanism underlying list-method directed forgetting thus differs in its developmental trajectory from that underlying retrieval-induced forgetting.

2. Item-method directed forgetting

Few studies have examined item-method directed forgetting in young children. Posnansky (1976) found better recall of TBR items than TBF items in both third and seventh graders, with no difference in the effect of the forget cue between the two age groups. Foster and Gavelek (1983) reported that even first graders recalled more TBR than TBF items, although the effect of the forget cue was smaller for first than for fifth graders. Regarding older adults' directed forgetting, several studies found a reliable difference between TBR and TBF items with increasing age. The difference, however, was smaller in older adults than in younger adults (Zacks et al., 1996; Earles and Kersten, 2002; Dulaney et al., 2004), which indicates that older adults show deficient directed forgetting in this type of task.

Together the results suggest that both young children and older adults show deficits in item-method directed forgetting. Following the strengthening view of item-method directed forgetting, these findings, however, do not imply inhibitory deficits in young children and older adults but, rather, may indicate differences in the degree to which the two age groups are able to strengthen relevant material.

2.13.2.6.3 Part-list cuing impairment

There seems to be only one study in the literature that examined part-list cuing impairment in young children. Zellner and Bäuml (2005) examined the detrimental effect of part-list cues in first graders, fourth graders, and young adults. All three groups showed reliable part-list cuing impairment with no difference in amount of forgetting across the three age groups. Moreover, in this experiment, part-list cuing impairment was directly compared with retrieval-induced forgetting. None of the three age groups showed any reliable difference between the detrimental effect of retrieval practice and the detrimental effect of part-list cuing.

In older adults, Marsh et al. (2004) found robust part-list cuing impairment in both younger and older adults across three experiments. If anything, the older adults showed stronger detrimental effects than the young adults and were disproportionately slow in the presence of part-list cues. This result suggests that part-list cuing impairment is not reduced in older adults. Part-list cuing impairment, like retrieval-induced forgetting, thus may be intact across most of the lifespan.

2.13.2.6.4 Summary

To date, relatively few studies have addressed the development of inhibition in human memory. From these studies a fair amount of knowledge has been gained regarding the development of inhibitory mechanisms as they occur in retrieval-induced forgetting, directed forgetting, and part-list cuing impairment. Unfortunately, there are no published studies to date in which the development of inhibitory processes involved in strength-induced forgetting and think/no-think impairment has been addressed, so that the current picture on the development of inhibition in memory is only fragmentary.

Still, current results clearly challenge the hypothesis of a general inhibitory deficit in young children and older adults by showing that both age groups show intact inhibition in some memory tasks. It thus seems that the picture of a general inhibitory deficit needs to be updated in favor of the picture of task-dependent inhibitory function. Specifying the exact nature of the inhibitory mechanisms that are intact in young children and older adults and of those that are deficient is a high priority for future research on the development of inhibitory function.

2.13.3 Conclusions

In the introduction, three inhibitory mechanisms were suggested to reduce accessibility of irrelevant memories: blocking, route deactivation, and item suppression (**Figure 1**). These mechanisms differ in whether they affect memories indirectly (blocking) or directly (route deactivation, item suppression), and whether they affect memories' retrieval routes (route deactivation) or their representation itself (item suppression). As a result, the three mechanisms also differ in the range of memory tests in which the effects of inhibition can be observed. While effects of blocking manifest themselves mainly in free-recall tests and effects of route deactivation in free- and cued-recall tests, effects of item suppression are present over a wide range of memory tasks, including recognition and independent-probe tests.

The results on the experimental paradigms reviewed in section 2.13.2 suggest that each of the three mechanisms plays a role in reducing irrelevant memories' accessibility. However, the results also suggest that none of the three mechanisms is responsible for the effects in all the paradigms. Rather, it seems that a multiplicity of mechanisms are at work to induce inaccessibility of irrelevant material across a wide range of situations. In strength-induced forgetting, for instance, inhibition seems to be realized by means of blocking, in which early recall of strengthened (relevant) material hinders subsequent recall of nonstrengthened (irrelevant) material. Consistently, forgetting is present mainly in free recall tasks and is absent in recognition tasks. Strength-induced forgetting thus is mediated by a relatively weak form of inhibition that affects the irrelevant material only indirectly. The same mechanism is likely to be involved in item-method directed forgetting, at least when following the strengthening view of this form of directed forgetting.

In list-method directed forgetting, a stronger form of inhibition is at work in which the retrieval routes between the irrelevant material and its cue(s) are affected directly. Accordingly, forgetting in this paradigm can be observed in free and cued recall tasks while no effects arise in recognition tests, which rely mainly on the items' representation itself. In strength-induced forgetting, the effects on the relevant and irrelevant material's accessibility are mediated by the same mechanism. In list-method directed forgetting, there is evidence for two separate processes, one process reducing accessibility of the irrelevant material and the other process enhancing accessibility of the relevant information. When operating in concert, these two processes can create very effective memory updating.

In retrieval-induced forgetting, inhibition is realized by suppressing the representation of the inhibited items themselves, thus making retrieval less effective regardless of which retrieval cue is employed. Consistent with this strong form of inhibition, the forgetting in this paradigm can be found across a wide range of memory tests, including recognition and independent probe tests. As in list-method directed forgetting, there is evidence for the action of two processes, a forgetting mechanism directed on the irrelevant material and an enhancement mechanism directed on the relevant information. Together, they induce a strong difference in accessibility between relevant and irrelevant material and thus induce effective memory updating. There is also evidence that the same inhibitory mechanism underlies the forgetting in the think/no-think paradigm and in part-list cuing, because in both cases the forgetting has been found not only to arise in free- and cued-recall tasks but to generalize to other tasks as well.

The evidence that different mechanisms mediate inhibition in the single paradigms motivates a taxonomy of the paradigms, in which the paradigms are partitioned into three subsets, one in which the forgetting is caused by blocking (strength-induced forgetting, possibly item-method directed forgetting), one in which the forgetting is caused by route deactivation (list-method directed forgetting), and one in which the forgetting is caused by item suppression (retrieval-induced forgetting, think/no-think impairment, and part-list cuing impairment; **Figure 8**). Although currently there is only restricted knowledge regarding the developmental aspects of inhibition in the single paradigms, the suggested taxonomy is at least consistent with current knowledge. Current knowledge suggests comparable developmental trajectories for retrieval-induced forgetting and part-list cuing impairment and a different trajectory for list-method directed forgetting. Item suppression and route deactivation thus may follow different developmental paths.

Besides the differences in underlying mechanism, the single paradigms also differ regarding the stage at which the inhibition takes place. In list-method directed forgetting, inhibition operates before the test during the encoding of the new relevant material. In retrieval-induced forgetting and think/no-think impairment, inhibition also operates before the test, either while selectively retrieving relevant information (retrieval-induced forgetting) or while trying to stop retrieval of irrelevant information (think/no-think impairment). In strength-induced forgetting, item-method directed forgetting, and part-list cuing impairment, the inhibition operates at test, either by blocking recall of irrelevant material (strength-induced forgetting, item-method directed forgetting) or by suppressing relevant material through covert retrieval of cue items (part-list cuing impairment).

It is the general goal of inhibition in memory to enhance accessibility of relevant material at the expense of the accessibility of the irrelevant material. This goal is realized very differently in different situations. The differences are reflected in the

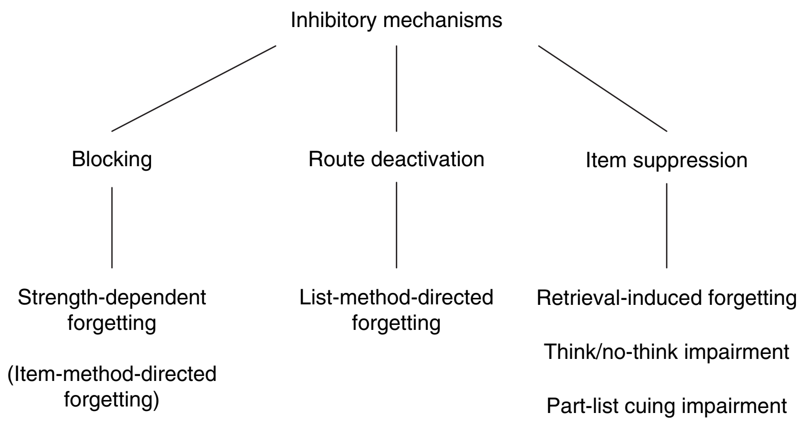

Figure 8 Taxonomy of inhibition paradigms. The taxonomy lists experimental paradigms in which some form of inhibitory mechanism is assumed to be crucially involved. The paradigms are partitioned according to which of the three mechanisms – blocking, route deactivation, and item suppression (**Figure 1**) – is supposed to mediate the inhibition.

diversity of mechanisms that mediate the effect in the single situations, and they are reflected in the varying stages at which the inhibition takes place. Together, the picture of a very flexible and goal-directed updating system arises, in which a multiplicity of inhibitory mechanisms operate at very different processing stages to overcome the problem of retrieval competition and interference and thus help memory function effectively. At the end of the nineteenth century, Ribot wrote that "Forgetfulness . . . is not a disease of memory, but a condition of its health and life" (Ribot, 1882: 61). The results reviewed in this chapter provide a vivid and detailed demonstration of the adequacy of this early view.

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