Retrieval inhibition in episodic recall

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Episodic forgetting can arise in a number of different situations. Recall of target material can be impaired if additional material is learned (interference), related information is repeatedly retrieved (retrieval-induced forgetting), or an instruction to intentionally forget the target material is provided (directed forgetting). The question arises which mechanisms underlie these different forms of forgetting and how they affect the binding of items and cues. We report results from experiments in which response latency analysis was used to distinguish between different forgetting mechanisms. The results suggest that interference is due to enhanced competition, whereas retrieval-induced forgetting and directed forgetting are mediated by a form of retrieval inhibition in which the binding between items and their cues is weakened. Furthermore, in both retrieval-induced forgetting and directed forgetting, the weakening could not be reduced by a repeated testing procedure, indicating that the inhibition is stable and long-lasting. We also studied the developmental course of episodic forgetting. Whereas children and adults showed similar susceptibility to interference and also similar effects of retrieval-induced forgetting, a developmental difference was found in directed forgetting. Mature directed forgetting was present only in adults and older children but not in younger children.

Introduction

Episodic forgetting refers to the impaired ability to remember information encoded in a particular spatial-temporal context. Such forgetting can arise in a number of situations. One type of situation is *interference*. Interference refers to situations in which the encoding of additional information - e.g., the names of new colleagues - is responsible for the poorer remembering of other encoded information - e.g., the name of an older colleague. Experimentally, interference has been investigated by letting subjects study one target list and several additional nontarget lists (see Crowder, 1976, for a review). The typical finding has been that later recall of the target list is impaired by both the prior learning (proactive interference) and the subsequent learning (retroactive interference) of nontarget information.

Tulving and Psotka (1971), for instance, let different groups of subjects study one target list and subsequently zero to five nontarget lists. After study of the lists, subjects were asked to remember all of the previously learned items. Recall rates for target items continuously declined with increasing number of learned nontarget lists. The learning of additional information caused retroactive interference for the previously learned target information.

A second type of situation in which episodic forgetting can arise is *retrieval-induced forgetting*. Retrieval-induced forgetting refers to situations in which the repeated retrieval of stored information - e.g., the repeated retrieval of the names of some students in a psychology course - is responsible for the later poorer remembering of the nonretrieved information - e.g., the names of those students whose names were not retrieved. Experimentally, retrieval-induced forgetting has been studied using the retrieval-practice paradigm (see Levy & Anderson, 2002, for a review). In this paradigm, subjects study items which they have to recall at a later point in time. Between learning and test, a subset of the previously studied material is repeatedly practiced. Such retrieval practice typically improves later recall of the practiced material but impairs recall of the unpracticed material, compared to a control condition in which no retrieval practice takes place.

Anderson, Bjork, and Bjork (1994), for instance, presented subjects items from several semantic categories. Then, half of the members of half of the studied categories were repeatedly practiced using word stem completion tests (e.g., Fruit - Or___). In a final category-cued recall test, the subjects were asked to recall all of the previously presented items. Unpracticed items from practiced categories (e.g., Fruit-Banana) showed lower recall rates than unpracticed items from unpracticed categories (e.g., Tree-Hickory). The retrieval of part of the previously learned material caused forgetting of the nonretrieved material.

A third type of situation in which episodic forgetting occurs is *directed forgetting*. Directed forgetting refers to situations in which a cue to forget a previously encoded information - e.g., the old telephone number of a friend - successfully leads to the forgetting of the outdated information. Experimentally, directed forgetting has been studied by letting subjects learn two item lists (see MacLeod, 1998, for a review). After study of list 1, subjects receive either a forget cue or a remember cue. In the forget condition, subjects are asked to forget the list as good as they can and instead learn a new item list. In the remember condition, they are asked to remember the list as good as they can and additionally learn a second list. Compared to the remember cue, the forget cue typically leads to poorer recall of list 1 items and better recall of list 2 items.

Bjork (1970), for example, examined the effect of a forget cue on the retrieval of syllable-word pairs. After presentation of two pairs, one group of subjects received the instruction to forget the prior pairs in the list. Another group of subjects received no such cue. Then, another set of two pairs was shown followed by a recall test for all four presented pairs. Recall for the second two pairs was better for subjects who had received the forget instruction, but recall for the first two pairs was better for subjects without such an instruction. The intention to no longer remember some previously encoded information caused directed episodic forgetting.

What are the mechanisms which mediate interference, retrieval-induced forgetting, and directed forgetting? There is fairly broad agreement in the literature that interference is due to a competition mechanism (Mensink & Raaijmakers, 1988; Raaijmakers & Shiffrin, 1981; Rundus, 1973). The main idea is that items which share a common cue compete for conscious recall if this cue is provided. The competition for a target item then is assumed to increase if new material is bound to the common cue, or if other material already bound to the common cue is strengthened. Such an increase in competition makes it harder for the target material to be recalled, i.e., forgetting arises.

There is also good agreement in the literature that retrieval-induced forgetting and directed forgetting are not the result of enhanced competition and thus are mediated by a different mechanism than interference. Indeed, it has repeatedly been suggested that retrieval-induced forgetting and directed forgetting result from retrieval inhibition (Anderson et al., 1994; Bjork, 1989; but see MacLeod, Dodd, Sheard, Wilson, & Bibi, in press, for suggestions for underlying noninhibitory mechanisms). Although the inhibition proposals impose restrictions on the way in which both retrieval practice and a forget cue cause forgetting (Bjork, Bjork, & Anderson, 1998), these proposals are not very explicit about the exact nature of the underlying inhibitory mechanisms. Indeed, a priori a number of possibilities arise about how exactly inhibition causes forgetting. Three possibilities are entertained in the present paper, weakening, unbinding, and slowing.

One way in which inhibition may cause forgetting is by means of a *weakening* process. In fact, inhibition may cause forgetting by weakening the binding between an inhibited item and its cue(s). Such weakening could affect the item's representation itself or the retrieval route(s) between the cue(s) and the item. In both cases, weakening would impair later recall of the inhibited item by making it harder for the item to exceed the recovery threshold. As a second possibility, inhibition might induce an *unbinding* of inhibited items by disconnecting items from their cue(s). As a result, the cue would become ineffective as a recall aid and thus forgetting would arise. In contrast to weakening, unbinding would cause forgetting not because of lowered recovery chances but rather because of a failure at the sampling stage of recall. Finally, as a third possibility, inhibition might cause forgetting by *slowing* down the retrieval of inhibited items. In such a case, the binding structure of an item would not be affected and only the mental processing of items would be hampered. Forgetting would arise mainly because of time restrictions in recall, be it through experimenter-imposed restrictions or personal time limits set by a subject himself.

This paper reports the results of three experiments designed to improve our understanding of the mechanisms of episodic forgetting. Experiment 1 addresses the issue of the exact nature of the inhibitory mechanisms proposed to underlie retrieval-induced forgetting and directed forgetting by using response latency analysis. Because weakening, unbinding, and slowing make different predictions on how inhibition affects response latencies (see below), this method permits a distinction between the three putative mechanisms. Whereas Experiment 1 focuses on the way in which inhibition causes forgetting, Experiment 2 addresses the issue to what extent an existing inhibition can again be eliminated. The question of whether the forgetting is reversible, or not, is examined by directly comparing the effect of repeated testing on retrieval-induced forgetting and directed forgetting. Because repeated testing has often been shown to improve recall performance (Payne, 1987), such a manipulation appears of particular importance in studying the reversibility of inhibition. Finally, Experiment 3 takes a look at the developmental course of episodic forgetting and investigates whether young children already show intact episodic forgetting. The effects of interference, retrieval-induced forgetting, and directed forgetting are examined. The results of the three experiments will help clarifying our picture about the similarities and differences between the different types of episodic forgetting.

Experiment 1

Rate of correctly recalled items, which is most often used to measure memory performance, cannot easily differentiate between forgetting mechanisms which operate on the sampling stage and forgetting mechanisms which operate on the recovery stage of memory retrieval. In fact, if someone is not able to remember an item in a particular situation, it is unclear whether this is due to enhanced competition or inhibition, and if due to inhibition, it is unclear whether the inhibition is caused by weakening, unbinding, or slowing. A better way to distinguish between sampling and recovery is response latency analysis. Response latencies measure at what point in time during recall the single items are recalled. For each item recalled, time from the onset of the recall period to the response is assessed. If response latencies follow an exponential function – and thus are consistent with the random-search model (McGill, 1963; Wixted & Rohrer, 1993) -, the resulting mean response latencies can be used to make inferences about processing time in retrieval, subjects' mental search sets, and the strength of items' memory representation.

For example, Rohrer, Wixted, Salmon, and Butters (1995) showed that mental processing speed influences response latencies. In their study, subjects performed a semantic fluency task whereby response latencies were recorded. Some subjects conducted a concurrent secondary task meant to occupy mental resources and to slow down general cognitive processing. In the dual-task condition, fewer items were generated from the semantic categories and the answers were given slower than in the single-task condition. Apparently, latencies increase if processing is slowed down.

Response latencies are also capable to identify an unbinding mechanism. Rohrer et al. (1995, Experiment 3) compared semantic fluency of Alzheimer's disease (AD) patients and healthy controls. In category fluency tasks, AD patients usually produce a disproportionately small number of specific exemplars (e.g. Tröster, Salmon, McCullough, & Butters, 1989). Therefore it was supposed that AD patients lose a number of interitem or cue-item associations and, therefore, retrieve items from a smaller search set than healthy subjects. Consistent with this hypothesis, mean response latencies for the AD patients were significantly shorter than those of controls, thus providing evidence for a reduction of mental search set size, i.e., an unbinding of items.

In another study, Rohrer and Wixted (1994) studied the relation between item strength and response latencies. Subjects were presented lists of six individually presented items with study time manipulated between lists. As expected, longer presentation times resulted in higher recall rates, presumably because of increased item strength. However, there was no effect of study time on mean latencies. This result indicates that manipulations of item strength affect only recall rate but not response latencies (see Rohrer, 1996, for a theoretical account of the effects of dual task, search set, and item strength on response latencies using the random-search model).

On the basis of these findings, we can use response latency analysis to distinguish between different forgetting mechanisms. Enhanced competition, for example, is known to emerge from a larger search set and, therefore, should show an increase in latencies (Wixted & Rohrer, 1993). The mechanisms of inhibition – weakening, slowing, and unbinding - are associated with changes in item strength, processing time, and mental search set size. Accordingly, in the case of weakening, no effect on response latencies should arise. By contrast, slowing should prolong response latencies and unbinding should reduce latencies by eliminating items from the search set. These predictions can be used to analyze the mechanisms which underlie episodic forgetting. Experiment 1 reports a response latency analysis of interference and retrieval-induced forgetting.

Method

Overview. There were two experimental conditions, the interference-practice condition and the control condition. In the interference-practice condition, subjects studied items from eight semantic categories and then recalled the single categories in succession given the category names as a retrieval cue. Retrieval-induced forgetting was assessed by comparing recall and latencies of tested-first and tested-last categories, thus mimicking the output interference variant of retrieval-induced forgetting (Bäuml & Hartinger, 2002). In the control condition, only two semantic categories were learned and tested. Interference was assessed by comparing recall and latencies of tested-first categories in the control condition and tested-first categories in the interference-practice condition.

Subjects. Participants were 17 psychology students from the University of Regensburg who fulfilled study requirements.

Material. Item lists were constructed from the word norms of Mannhaupt (1983) and Scheithe and Bäuml (1995). We chose 40 concrete categories, 16 target categories and 24 nontarget categories. From each category, six items were chosen. Items from rank order 1 to 4 were excluded to prevent guessing. Strong associations between items and strong similarities between categories were avoided. Categories were grouped into eight sets of two target categories and four sets of six nontarget categories. Study lists in the interference-practice condition consisted of one set of target categories and one set of nontarget categories. Study lists in the control condition consisted of one set of target categories only.

Design. Each subject was exposed to four trials in the interference-practice condition and four trials in the control condition. Each trial consisted of a presentation phase in which items from two (control condition) or eight (interference-practice condition) categories were studied, a subsequent distractor task, and a final category-cued recall test. Order of conditions was balanced across subjects. After four trials, there was a 5 min break for recreation.

Each set of target categories was equally often used in the control condition and the interference-practice condition, and each target category was equally often tested in the first and the last position in the final cued recall test. Additionally, in the interference-practice condition, each set of target categories was equally often combined with each set of nontarget categories. Item order within a category was randomly determined and remained constant for four subjects each.

Procedure. Items together with their category name were individually shown on a computer monitor for 3 sec each (e.g. FRUIT – Orange). Item presentation was category blocked, that is, all six items from a category were shown adjacently. In the interference-practice condition, target categories were presented as the fourth and the fifth category, that is, in the middle positions of the item list. In the control condition, only the target categories were shown. Instead of studying the categories one to three and six to eight, subjects did a simple number ordering task. Category order was balanced across subjects.

After list presentation was completed, a distractor task followed in which, for one minute, famous persons had to be rated regarding their attractiveness.

Thereafter, the recall test started. A category name was given and subjects had to remember all the previously learned items from the cued category for 30 sec. Then, the next category followed. One of the two target categories was tested on testing position 1, the other on testing position 8. There were three minutes between the recall tests of the two target categories, during which subjects in the interference-practice condition recalled the six nontarget categories and subjects in the control condition solved arithmetic problems.

Subjects gave their responses verbally which were recorded by a computer program in a pcm-wav format with a sampling rate of 44.1 kHz and a resolution of 16 bit. Latencies were assessed by means of the computer program Cool Edit 2000 (version 4.1, Syntrillium Software Corporation, Phoenix, AZ, USA), whereby the voice onset of each recalled item was manually located in the spectrogram. Latencies were always rounded up to the next second. Mean latencies were acquired by estimating the parameters of the cumulative exponential function

$$F(t) = N(1-e^{-(t-c)/\tau})$$

to disentangle the time until the memory search starts and the item sampling time. In this function, parameter c reflects the intercept on the x-axis assessing the time for establishing the search set and starting the memory search, parameter N reflects the asymptote assessing the potential for recall, and parameter τ reflects the slope of the function assessing the speed of recall. If response latencies follow such an exponential, parameter τ equals the mean response latencies in an experimental condition (e.g. Wixted & Rohrer, 1993).

Results and Discussion

Interference effects

To address interference, we compared recall of the tested-first category in the control condition with recall of the tested-first category in the interference-practice condition. Mean recall in the control condition (79.4%) was somewhat higher than mean recall in the interference-practice condition (74.3%), but the difference was not reliable [$t(16)=1.64$; $p=.12$]. Thus, although the learning of six additional categories tended to impair target item recall, the impairment was not significant.

Cumulative recall frequencies of tested-first categories in the control and the interference-practice condition are depicted in Figure 1. The interference-practice condition shows a slightly lower asymptote and a smaller slope than the control condition. Corresponding parameter estimates are summarized in Table 1. The asymptotic standard error of estimation was .008 in the control condition and .009 in the interference-practice condition. The estimations for the asymptote (parameter N) yielded a significant difference between the control condition (78.7) and the interference-practice condition (73.6) [$t(54)=15.65$, $p<.001$], thus confirming the observed tendency that recall in the interference-practice condition was somewhat lower than in the control condition.

The time until the memory search started (parameter c) was 1.69 in the control condition and 1.64 in the interference-practice condition. This difference in initiating memory search was not reliable [$t(54)=.89$, $p>.1$]. The estimations for the parameter τ indicating the speed of memory retrieval in the two conditions yielded 3.45 in the control condition and 4.39 in the interference-practice condition, which is a significant difference [$t(54)=-8.56$, $p<.001$]. Thus, it took longer to reach asymptote if a larger number of categories had been learned.

Table 1
Parameter estimates (with standard errors) for the tested-first categories in the control condition and the interference-practice condition. N: asymptote parameter, c: initiation parameter, τ: slope parameter.

	N	c	τ
control condition	78.7% (.21)	1.69 (.04)	3.45 (.06)
interference-practice condition	73.6% (.25)	1.64 (.05)	4.39 (.09)

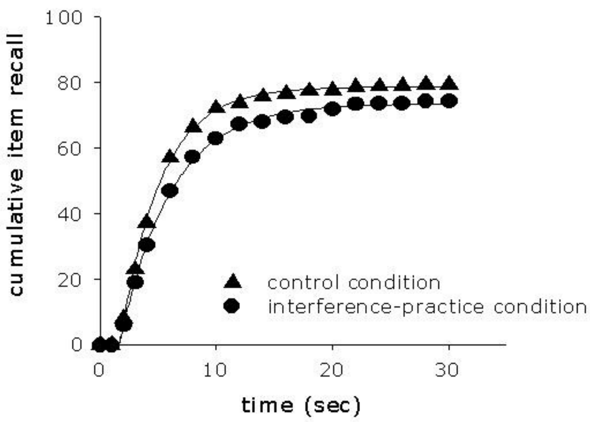

Figure 1. Interference: Mean cumulative recall and the best-fitting exponentials for the tested-first categories in the control condition and the interference-practice condition.

Although the effect of learning additional material was only marginal for recall frequencies, we found a clear increase in response latencies when additional material was learned. This indicates that, in the interference-practice condition, items were drawn from a larger search set than in the control condition. This result replicates prior findings (Wixted & Rohrer, 1993) and is consistent with the view that interference is due to enhanced competition arising from the encoding of additional material.

Retrieval-practice effects

To address retrieval-induced forgetting, we compared recall rates of target categories when tested first and when tested last in the interference-practice condition. If a category was tested first 74.3% of the items were correctly recalled, if it was tested last 65.0% of the items were recalled. This difference was significant [$t(16)=2.84$, $p<.05$], thus replicating the standard result of retrieval-induced forgetting.

Cumulative recall frequencies for tested-first and tested-last categories in the interference-practice condition are depicted in Figure 2. The tested-last category shows a lower asymptote than the tested-first category, but both categories have similar slopes. Table 2 summarizes the results of the parameter estimates. The standard error of estimation was .009 for the tested-first categories and .017 for the tested-last categories. The estimates of the asymptote parameter N (73.6 vs. 62.7) yielded a significant difference between testing positions [$t(54)=-43.03$, $p<.001$], confirming the recall frequency result above. The initiation parameter c was 1.64 for both tested-first and tested-last categories [$t(54)=-.08$, $p>.1$]. The slope parameter τ was 4.39 for the tested-first and 4.25 for the tested-last categories [t(54)=-1.09, p>.1] indicating that mean latencies did not change with retrieval practice.

Although a clear forgetting effect existed in the frequency data, latencies were largely unaffected. This suggests that retrieval-induced forgetting in the present experiment was neither mediated by a change in mental search set size nor by a change in sampling time. Therefore, neither unbinding, which would reduce set size, nor slowing, which would prolong processing time, should underlie the effect. The most simple explanation of the present results is that the forgetting was based on a weakening mechanism which reduces the strength of inhibited items and has no effect on inhibited items' response latencies.

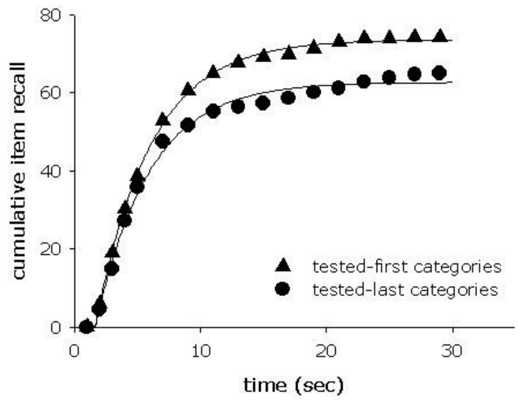

Figure 2. Retrieval-induced forgetting: Mean cumulative recall and the best-fitting exponentials for the tested-first and the tested-last categories in the interference-practice condition.

Table 2.
Parameter estimates (with standard errors) for the tested-first and the tested-last categories in the interference-practice condition. N: asymptote parameter, c: initiation parameter, τ: slope parameter.

	N	c	τ
tested-first category	73.6% (.25)	1.64 (.05)	4.39 (.09)
tested-last category	62.7% (.05)	1.64 (.11)	4.25 (.21)

Retrieval-induced forgetting is usually attributed to the inhibition of interfering items in the retrieval practice phase. For example, when a particular category is tested, items from other categories also come to mind and interfere with the current retrieval. To release this interference, these items are suppressed (Anderson et al., 1994; Anderson & Spellman, 1995). Our results add to this interpretation that the suppression is realized by a weakening mechanism in which the strength of the binding of inhibited items to their cue(s) is reduced.

Bäuml, Zellner, and Vilimek (2003) reported another retrieval-induced forgetting experiment in which Anderson et al.'s (1994) retrieval-practice paradigm was used. Subjects studied a categorized item list where each category included items from two subcategories (for example, the category *"professions"* consisted of *"workmen"* and *"academics"*). For a subset of the studied categories, subjects thereafter practiced the items of one of the two subcategories. In the later test phase, subjects were asked to recall all of the previously learned items. They were cued by the subcategory labels, so that the retrieval of practiced items and unpracticed items could be separated. The results showed the standard pattern of retrieval-induced forgetting with recall improvement for practiced items and recall impairment for unpracticed items. More interesting, they showed no effect of retrieval practice on response latencies, either for the practiced or the unpracticed items. These results confirm the suggestion from Experiment 1 that retrieval-induced forgetting is mediated by a weakening mechanism which reduces the strength of the bindings of inhibited items.

Bäuml et al. (2003) also reported the results of a directed forgetting experiment. Subjects studied two lists of items and got an interlist instruction which stated whether the just presented list was to forget or to remember. The results showed the standard pattern of directed forgetting with improved list 2 recall and impaired list 1 recall. Besides, the results were again consistent with a weakening hypothesis indicating that inhibition in directed forgetting also reduces binding strength.

In summary, our latency experiments show that there is not a unitary mechanism in episodic forgetting. Interference effects arise because of competition from irrelevant material, whereas retrieval-induced forgetting as well as directed forgetting are due to a weakening process.

Experiment 2

Episodic forgetting usually does not refer to a permanent memory state. In fact, if an item cannot be remembered in a particular situation, a change in the spatial-temporal context or new retrieval cues may facilitate the item's retrieval and thus reverse the forgetting.

Retroactive interference often shows spontaneous recovery of forgotten items when a particular amount of time elapses after learning of the additional material. For example, Wheeler (1995) used a target list with items from two semantic categories. In the interference condition, an additional list was learned as an interpolation list. One of the two target categories was tested immediately after study of the interpolation list, the other target category was tested 30 min later. Whereas performance in the control condition in which no interpolation list was learned declined over the retention interval, subjects in the interference condition recalled more items after 30 minutes than immediately after the study phase. Obviously, the detrimental effects of learning additional items was attenuated after a while.

Studies concerning retrieval-induced forgetting also show that the retrieval-practice effect can disappear if practice and test are separated by a sufficient amount of time. For example, MacLeod and Macrae (2001) found that retrieval-induced forgetting is no longer existent when the retention interval between practice and test is as long as 24 hours. But it has also been shown that the retrieval-practice effect lasts at least for 20 minutes (Anderson et al., 1994). Retrieval-induced forgetting thus seems to be more stable than interference effects, though nevertheless reversible.

In the case of directed forgetting, it is known that the effect of the forget instruction can be eliminated when a subset of the learned items is given as retrieval cues at the time of test. Goernert and Larson (1994) presented 40 items with a midlist cue to remember or to forget the first 20 items. At test, 0, 4, or 8 list 1 items were given and subjects were instructed to recall the remaining list 1 items. Whereas there was a clear disadvantage of forget items in the uncued condition, remember and forget items were equally well recalled in the 4-cue and the 8-cue condition. Forget items seemed to be re-activated by the part-list cues and, as a consequence, forgetting disappeared. These examples show that, at least in principle, all three forms of episodic forgetting are reversible.

Another method which is known to improve memory performance over time and which could possibly also reduce forgetting is the repeated testing procedure. In repeated testing, subjects try to remember a previously presented list for a number of times without intervening study opportunities. Usually, repeated testing yields increasing recall levels across successive tests (see Payne, 1987, for a review). The increase is most readily obtained with pictorial materials or with imaginal encoding instructions (instructions to create an image of the material), but verbal material and nonimaginal study strategies can also produce the effect (e.g., Roediger & Payne, 1985). We examined whether the repeated testing pattern generalizes to inhibited items and, in particular, whether repeated testing can result in a release of inhibition.

Apart from enlightening the issue of reversibility of forgetting, the experiment can also help to specify the nature of the underlying forgetting mechanism. If inhibition is due to a weakening process, as argued in Experiment 1, forgetting cannot be undone by successive retrieval attempts, because weakening is meant to be stable at least for time intervals up to 20 minutes (Anderson et al., 1994; Anderson & Spellman, 1995). But if weakening of items is controlled by some strategic aspects, for example a mental context change (Sahakyan & Kelley, 2002), then the repeated chance to remember the items should provide an opportunity to quit an ineffective strategy and, for example, reinstate the appropriate context. Thus, if a forgetting mechanism is strategy dependent, a reduction in forgetting should occur.

To test these hypotheses, we conducted a directed forgetting experiment (Experiment 2a) and a retrieval-induced forgetting experiment (Experiment 2b).

Experiment 2a: Directed forgetting

A directed forgetting experiment was conducted in which subjects learned two item lists and, dependent on condition, a remember or forget cue was given between the learning of list 1 and list 2. One group of subjects remembered the items in three successive tests, whereas another group of subjects remembered the items only once. This later group worked through distractor tasks when the first group received memory test 1 and memory test 2 and thus served as a control of spontaneous recovery effects over the elapsed time interval.

Method

Subjects. Participants were 42 male and 42 female adults (mean age = 27.8) who participated on a voluntary basis. Subjects were tested individually.

Material. Two word lists were constructed each consisting of 12 unrelated two-syllables nouns. All participants learned both lists. Order of word lists and order of items within lists was held constant across all subjects.

Design and procedure. Half of the subjects were assigned to the remember condition, the other half to the forget condition. In each condition, 21 subjects were tested just once (1-test condition) whereas the other 21 subjects were tested three times in succession (3-tests condition).

At the outset, participants were told that they would hear a list of words and that they should try to remember the words for a later memory test. Then the first list was read with a rate of 2 sec per item. After the first list was presented, subjects in the remember condition were told that they should continue remembering that list and that they next would hear another list that they should also try to remember. Participants in the forget condition were told that the first list had been for practice only and that they should try to forget this list. They would now hear the list on which they would be tested. Approximately 15 sec elapsed during the delivery of the interlist instructions. Then the second list was presented.

After the last item of the second list was read, the test instruction was given. In the 3-tests condition, subjects were told that sometimes memory is better than they would suppose. Therefore, in the memory test, they would get three opportunities to remember the studied items. Subjects were also instructed not to stop trying to retrieve items because some items would come to mind only in a while. Then subjects were told that they should remember only the items from the first presented list. For subjects in the forget condition, it was explicitly stated that the first list actually was not a practice list but that the instruction had been an experimental manipulation. Finally, subjects were told that later they would be asked to remember the second list, too. These instructions took about 1 minute. Then the three recall tests were administered. Subjects had 90 seconds to remember the words of the first list and then paused for another 60 seconds. This procedure was repeated three times except that after the third test, no further break was included but subjects were asked to remember the second presented list for 90 seconds.

In the 1-test condition, subjects were told that before they would be asked to remember the items, they should first work through some other tasks. No indications were given regarding the kind of memory test that would follow. Subjects had five minutes to answer as many items as they could from the international PISA test items. Then they got the test instructions which stated that they should first try to remember as many items as they could from the first presented list. Again, subjects in the forget instruction were explicitly briefed about the status of this list. There were 90 seconds to remember the first list and then another 90 seconds to remember the second list.

Results and Discussion

Only list 1 item recall is reported. First, we compared the first and the last test trial in the 3-tests condition and examined whether the directed forgetting effect was reduced with repeated testing. In the first test, 38.1% of the items in the remember condition and 28.6% of the items in the forget condition were correctly recalled. In the third test, 39.7% of the remember items and 32.9% of the forget items were recalled (see Figure 3, Table 3). We conducted an analysis of variance with the between-factor instruction (remember, forget) and the within-factor test number (first test, last test). The ANOVA yielded a significant main effect of instruction [$F(1,40)=4.5$; $MSE=.031$; $p<.05$] and a significant main effect of test number [$F(1,40)=4.8$; $MSE=.004$; $p<.05$]. This result shows that the manipulation of instruction was successful and less first list items were recalled in the forget condition than in the remember condition. The result also shows that repeated testing was successful and improved item recall. Most interesting, the interaction between instruction and test number was not reliable [$F(1,40)=1.0$; $MSE=.004$; $p=.31$] indicating that the amount of directed forgetting did not change with repeated testing.

We additionally examined whether directed forgetting showed spontaneous recovery. We compared recall in the first test of the 3-tests condition with recall in the 1-test condition. In the 3-tests condition, 38.1% of the items in the remember condition and 28.6% of the items in the forget condition were correctly recalled. In the 1-test condition, recall rate was 31.4% in the remember condition and 19.0% in the forget condition. The analysis of variance with the two between-factors instruction and test condition yielded a significant main effect of instruction [$F(1,80)=15.1$, $MSE=.017$; $p<.001$] and a significant main effect of test condition [$F(1,80)=8.4$, $MSE=.017$; $p<.01$]. Indeed, recall levels in the 1-test condition were lower than in the 3-tests condition, thus no spontaneous recovery but rather forgetting occurred over the elapsed time interval. The interaction between instruction and test condition was not reliable [$F(1,80)<1$], indicating that the amount of directed forgetting did not vary with the retention interval.

Table 3.
List 1 recall rates (and standard errors) in the 1-test condition (only test) and in the 3-tests condition (first test and third test).

	1-test	3-tests (1st)	3-tests (3rd)
remember	31.4% (3.0)	38.1% (3.4)	39.7% (3.1)
forget	19.1% (2.3)	28.6% (2.3)	32.9% (2.5)

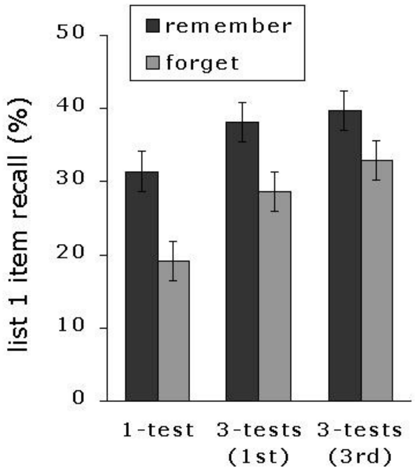

Figure 3. Directed Forgetting: List 1 recall rates in the 1-test condition (only test) and in the 3-tests condition (first test and third test).

In summary, no reduction of directed forgetting was found, neither over time nor over successive tests. These results cannot easily be reconciled with strategic approaches of directed forgetting, because ineffective strategies should be abandoned over three recall tests. The results are better explained by a weakening mechanism inducing some longer-lasting reduction in binding strengths.

Experiment 2b: Retrieval-induced forgetting

In a second experiment with the repeated testing procedure, we examined whether retrieval-induced forgetting can be eliminated by successive recall tests. In this second study, there was only a 3-tests condition and we restricted our analysis to a within-subjects comparison of the first and third recall test.

Method

Subjects. Participants were 48 adults (age range: 20-30) who participated partly on a voluntary basis and partly in fulfilling study requirements. Subjects were tested individually.

Material. Two item lists (A and B) were constructed by using items from the Deese-Roediger-McDermott (DRM) association lists (Roediger & McDermott, 1995). Half of the subjects learned list A, the other half learned list B. For each list, ten items of each of four DRM lists were selected, resulting in two 40-item lists. List A consisted of other DRM lists than list B. The DRM lists' critical items were used as category cues.

Design and procedure. The study followed a 3 x 3-design with the two within-factors item type and test number. The experiment consisted of three phases: a study phase, a retrieval-practice phase, and a test phase. In the retrieval-practice phase, half of the items of half of the categories were retrieval practiced (rp+ items). This practice yields two other item types, unpracticed items from practiced categories (rp- items) and unpracticed items from unpracticed categories (nrp). The test phase consisted of three successive memory tests with distractor tasks in between. Practiced categories and practiced items within categories were balanced across subjects as well as test order of categories.

Items were presented in a presentation booklet with one item per page. Item order followed a blocked randomization where every block consists of one item per category. One item order was used for half of the participants, the reverse order for the other half. Items were presented in a category-item format with a DRM list's critical item as the category label (e.g. WINDOW – open).

Each exemplar together with its category label was presented for 5 sec after which time the subjects received a signal to turn the page. After all 40 items had been studied, subjects counted backwards for 30 sec. Then the retrieval practice followed and five items from each of two categories were practiced. This was done by means of a practice booklet where on each page the unique word stem of a presented item with its category label was provided and had to be completed. The items were practiced in two consecutive blocks with no break in between. The order of the items within a block was random and each practiced item had to be retrieved once within each block. Retrieval practice was followed by two trail making distractor tasks taking about 2 minutes.

Then subjects recalled the initially learned list. A four-page test booklet was supplied with one category cue on each page. Subjects had 75 sec to remember a category's items, then they turned the page and recalled the next category's items. After all four categories were tested, another distractor task was administered where for 3 minutes the attractiveness of some well-known people were rated. Then subjects remembered the list again with the same procedure as in test 1. After test 2, subjects rated the competencies of well-known people for another 3 minutes. Thereafter they accomplished test 3.

Results and Discussion

We report the results of test 1 and test 3 only. In the first recall test, 66.7% of the rp+ items, 37.7% of the rp- items, and 45% of the nrp items were recalled. In the last test, recall rates were 67.1%, 43.1%, and 50.1%, for rp+, rp-, and nrp items, respectively (see Figure 4).

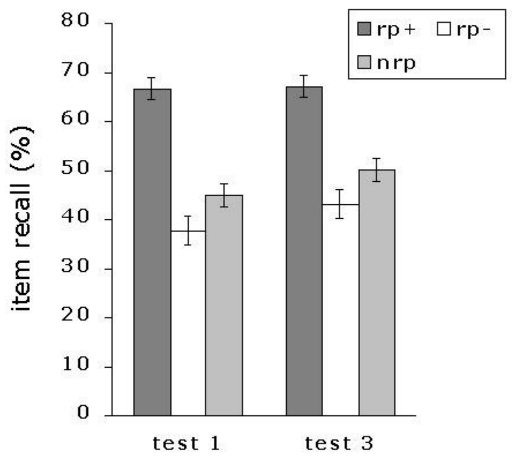

Figure 4. Retrieval-induced forgetting: Item recall as a function of item type and test number.

First, we analyzed whether the facilitative effect of retrieval practice changed over test trials. We conducted a 2 x 2 – ANOVA with item type (rp+, nrp) and test number (first test, third test) as within factors. The analysis yielded a significant main effect of item type [$F(1,47)=51.7$; $MSE=.035$; $p<.001$]. Neither the main effect of test number [$F(1,47)=2.7$;

MSE=.014; p=.11] nor the interaction between the two factors were reliable [F(2,94)=2.7; MSE=.010; p=.11]. These results replicate the facilitative effect of retrieval practice but fail to show recall improvement over repeated test trials. Particularly interesting, the non-significant interaction between item type and test number indicates that the facilitative effect did not vary with test number.

Next, we tested whether the amount of forgetting was reduced with repeated testing. A 2 x 2 – ANOVA with item type (nrp, rp-) and test number (first test, third test) as within-factors yielded significant main effects of item type [F(1,47)=7.0; MSE=.035; p<.05] and test number [F(1,47)=30.6; MSE=.004; p<.001] but no reliable interaction between the two factors [F(1,47)<1]. This result indicates that retrieval practice impaired recall of unpracticed items but repeated testing improved recall. The lack of an interaction between item type and test number shows that the amount of retrieval-induced forgetting was not reduced through repeated testing.

The results of the retrieval-induced forgetting experiment mimic those of the directed forgetting experiment by showing that the inhibition cannot be reversed through repeated testing. Therefore, the results are consistent with the view that both forms of inhibition are due to a long-lasting weakening process in which item strength of inhibited items is reduced. The results disagree with the hypothesis that inhibition in the two paradigms is due to strategic shifts, like a mental context change, because strategies are at least partially under conscious control and should be modifiable if necessary.

Experiment 3

In developmental studies of declarative memory, it has often been found that episodic memory shows substantial improvement between 6 and 12 years (Schneider, 2000). Changes in the available resources, in domain knowledge, in strategy use, or in metamemory have been made responsible for this development (Schneider & Pressley, 1997). Concerning episodic forgetting, interference effects and directed forgetting have been the primary focus of recent research in this area. However, no study of the developmental course of retrieval-induced forgetting has been done to date.

There are a number of studies in which the developmental change of interference has been investigated. Usually, it is assumed that the resistance to interference becomes more and more effective with age (Dempster, 1993) and, therefore, forgetting is reduced. Recently, Kail (2002) conducted a meta-analysis based on 26 Brown-Peterson interference studies including 86 data sets. He found that interference effects substantially decrease between 4 and 13 years.

Several studies examined children's directed forgetting. In these studies, it has been shown that young children are not able to intentionally forget material from episodic memory when cued to do so. In fact, first and third graders fail to show directed forgetting and show hardly any effect of the forget cue at all. Mature directed-forgetting performance, however, is present from fifth grade on (Bray, Justice, & Zahm, 1983; Harnishfeger & Pope, 1996).

At first glance, the increasing resistance to interference and the efficient utilization of a forget cue may appear related and to be mediated by the same mechanism. This holds because both the reduction of interference and the efficient directed forgetting reflect an attenuation of the interfering effects of previously learned material. Schneider and Pressley (1997), for example, relate both phenomena to the increasing functional capacity of working memory. This suggests that children who can resist proactive interference, should also be able to ignore interfering items when cued to do so.

Other researchers instead suggest that it is important to distinguish resistance to interference from directed forgetting (Wilson & Kipp, 1998). Resistance to interference is thought of as a gating mechanism controlling which items are included into the memory search set. The ability to intentionally forget, on the other hand, relates to the ignoring of irrelevant information in the search set during the retrieval phase (but see Experiment 1).

From this perspective, both processes are fundamentally different and, therefore, may also show different developmental courses.

To test whether the ability to forget intentionally and the ability to resist interference develop in parallel, we conducted an experiment where the same procedure and the same material were used to measure resistance to proactive interference and directed forgetting. We tested second graders and fourth graders, because in this age period mature directed-forgetting normally emerges. As a third study question, we also included a retrieval-practice experiment with identical item material and procedures. Representatively, method and results of the interference part of the study are outlined in the following. The directed forgetting and retrieval-induced forgetting results were reported elsewhere (Zellner & Bäuml, 2003) and will be summarized thereafter.

Method

Participants. Twenty-four second graders (age range: 7-8; M age = 7.4 years, SD = .49 years; 15 males, 9 females) and 24 fourth graders (age range: 9-10; M age = 9.3 years, SD = .46 years; 14 males, 10 females) participated in the experiment. They were recruited from a primary school near Regensburg, Germany, and participated on a voluntary basis. Additionally, 24 psychology students at the University of Regensburg (M age = 23.2 years, SD = 2.6 years; 5 males, 19 females) participated as an adult control group.

Material. Items were selected from German association norms for children in second grade, children in fourth grade, and adults (Hasselhorn & Grube, 1994). Different norms are available for the different age groups. The norms indicate which items are the most frequent responses to particular cue items in a free association task. The cue items in this experiment were chosen from four different semantic categories. From each of the four categories, two cue items were selected (for example, *"horse"* and *"owl"* from the category *"animals"*), and for each cue item a list was constructed by choosing eight strong associates to the particular cue. In this way, eight lists, each consisting of eight items, were created. For the adults, lists consisted of ten items per list to avoid a ceiling effect.

Design. There were two experimental conditions, a control condition and an interference condition. In the interference condition, two lists from the same semantic category were studied successively, whereas in the control condition only one item list was presented. Each of the four categories were equally often used in the two conditions and each of the two lists of the same category served equally often as list 1 and list 2 in the interference condition or as the one presented list in the control condition. Half of the participants started with the interference condition, the other half started with the control condition.

Procedure. At the outset, children were told a little story about the content of the lists. The story varied slightly with the employed category. For example, for the category *"tools"*, the instruction said: "Yesterday, Suzanne helped her grandfather to do some workings at home. Thereafter, Suzanne recorded onto this tape here what she had seen at her grandfather's house. You can now listen to the tape. Try to remember everything that Suzanne mentioned." Then, an audio tape was played where a female voice spoke the eight items of the list. They were spoken at an exposure rate of 2 sec per item. The order of the words was held constant.

In the interference condition, the tape was stopped after the presentation of the eighth word and the interlist cue was provided which stated that subjects should try to remember these words and should try to remember the next words on the second tape as well. Then, tapes were changed and the second list was presented. Thereafter, a trail making task was administered for 2 min as a distractor task. In the control condition, subjects only listened to one list and then got the trail making task. After the distractor task, recall was assessed. Subjects were asked to recall as many of the words as they could from the last tape (list 2) which was the only tape in the control condition. Subjects had 1 min for this recall. All subjects comfortably finished their recall before the recall period ended. Then subjects in the interference condition were also asked to recall as many words as they could from the first tape (list 1). Recall was written down by the experimenter. There was a break of 2 min between the two experimental conditions.

For the adults, the procedure was identical except for some small changes to adjust level of difficulty. First, adults received ten items per list instead of eight. Second, the adults' distractor task was more demanding. Instead of trail making they solved some arithmetic problems. And third, the adults' retention phase was prolonged to a duration of 5 minutes. In all other aspects, the procedure was identical to the procedure used in children.

Results and Discussion

Second graders recalled 43.8% of list 2 items in the control condition and 34.4% of list 2 items in the interference condition. Fourth graders showed recall rates of 55.7% and 34.9%. Adults recalled 79.6% of the items in the control condition and 72.1% of the items in the interference condition (see Figure 5).

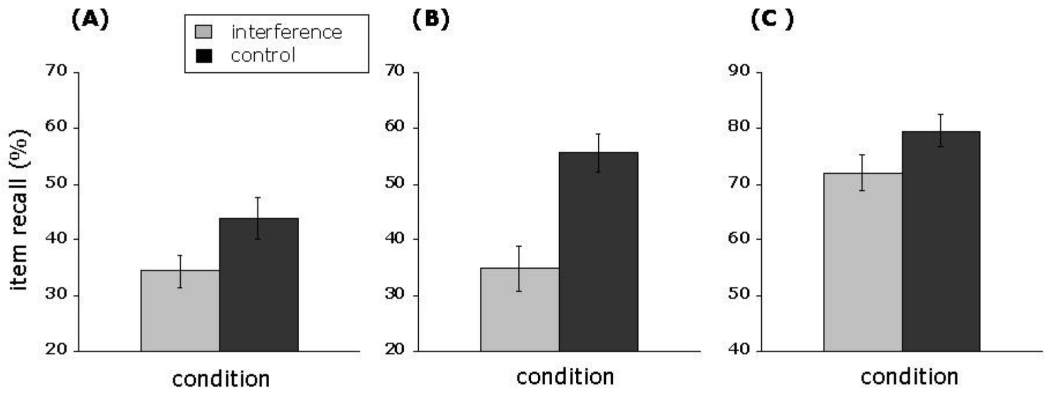

Figure 5. Interference: Item recall in the control and the interference condition for grade 2 (A), grade 4 (B), and adults (C).

To test for differences in proactive interference, we conducted a 3 x 2 – ANOVA with the between-factor age group (second graders, fourth graders, adults) and the within-factor condition (control, interference). There were significant main effects of age group [$F(2,69)=53.3$; $MSE=.031$; $p<.001$] and condition [$F(1,69)=23.4$; $MSE=.024$; $p<.001$] but no reliable interaction between the two factors [$F(2,69)=2.6$; $MSE=.024$; $p=.08$]. These results show a robust interference effect and additionally suggest that the susceptibility to interference did not decrease with age group. If anything, the present results show a tendency for more interference in fourth graders than second graders.

With the same material and similar procedures we also examined the developmental course of directed forgetting (Zellner & Bäuml, 2003). Concerning directed forgetting, we largely replicated prior results showing that directed forgetting develops over the elementary school years (Wilson & Kipp, 1998). In our study, second graders did not show any effect of a cue to forget a previously presented list, whereas fourth graders and also adults showed impaired recall of list 1 as well as improved recall of list 2. Thus, whereas we did not find a difference in the children's interference susceptibility, we found differences in their ability to show directed forgetting. This dissociation supports Wilson and Kipp's (1998) proposal that interference and directed forgetting are not mediated by the same mechanism.

We also examined children's retrieval-induced forgetting (Zellner & Bäuml, 2003). Comparing retrieval-induced forgetting in second graders, fourth graders, and adults, we received a strikingly parallel pattern of results over all three age levels. Retrieval-induced forgetting was effective for all three subject groups and was about the same in the single age groups. This result suggests that retrieval-induced forgetting is maturely developed even in the youngest children. Whereas this result parallels the result form the interference study, it is clearly different from the result of the directed forgetting study. This difference suggests that inhibition in retrieval-induced forgetting and inhibition in directed forgetting are not identical.

Previous studies showed that memory processes involving a low amount of controlled processes develop earlier than memory processes involving a high amount (e.g., Haberlandt, 1999). Our results concerning the two inhibition mechanisms fit well into this picture. Indeed, directed forgetting occurs with intentional effort, is dependent on conscious control, and places a drain on attentional capacity (Bjork, 1989; Conway, Harries, Noyes, Racsma'ny & Frankish, 2000). It thus should depend to a larger extent on controlled processes than retrieval-induced forgetting, which reflects unintentional inhibition, does not depend on conscious control, and seems to require only little attentional capacity (Bjork et al., 1998; Aslan & Bäuml, 2004). Consistently, we found retrieval-induced forgetting to develop earlier than directed forgetting.

General Discussion

One of the goals of the present paper was to examine to what extent different forms of episodic forgetting are caused by similar or different cognitive mechanisms. We studied interference, retrieval-induced forgetting, and directed forgetting across several experiments and provided evidence that the three forms of episodic forgetting are caused by different mechanisms. We argue that interference is due to enhanced competition, whereas retrieval-induced forgetting and directed forgetting are due to two different types of inhibitory mechanisms.

Results from prior work already indicated that interference is caused by enhanced competition (Mensink & Raaijmakers, 1988; Raaijmakers & Shiffrin, 1981; Rundus, 1973). The main assumption here is that items which are bound to a common cue compete for conscious recall, and thus recall of a target item is impaired if new items are bound to the common cue or already bound nontarget items are strengthened in their representation. Enhanced competition is proposed to not only impair a target item's recall chances but, in addition, to lead to slower response latencies for the target material (Rohrer, 1996). The results of Experiment 1 support this proposal by showing that the additional learning of nontarget material reduces recall of target material and, simultaneously, leads to an increase in the items' response latencies. The latter finding is consistent with results from prior work which demonstrated increased response latencies in proactive interference (Wixted & Rohrer, 1993) and increased response latencies with increases in study list length (Rohrer, 1996).

Results from several previous studies suggest that, in contrast to interference, retrieval-induced forgetting is not due to enhanced competition but rather is caused by retrieval inhibition (Anderson et al., 1994; Anderson & Spellman, 1995). The main idea here is that if a subset of previously learned material is to be retrieval practiced, then the not-to-be-practiced material interferes and, in order to reduce this interference, is suppressed. Although this concept of inhibition imposes restrictions on experimental data (Anderson et al., 1994; Anderson, Green, & McCulloch, 2000; Bäuml, 1998, 2002; Bäuml & Hartinger, 2002), it is left open what exactly the nature of the inhibition is.

In Experiment 1 we used response latency analysis to distinguish between three simple inhibition proposals, weakening, unbinding, and slowing. Unbinding predicted that inhibition induces a decrease in response latencies, slowing predicted an increase in latencies, and weakening predicted a null effect in response latencies. The results of Experiment 1 and of an additional experiment (Bäuml et al., 2003) showed that inhibition in retrieval-induced forgetting affects only recall frequencies but has no effect on response latencies at all. This pattern is consistent with the view that inhibition in retrieval-induced forgetting reduces the strength of the binding between an item and its cue(s) or, alternatively, reduces the strength of the item representation itself. We found no evidence that inhibition disconnects items from their cue(s), or slows down the whole retrieval process.

Like retrieval-induced forgetting, directed forgetting has also been explained in terms of inhibition (Bjork, 1989). Directed forgetting refers to a situation in which a previously encoded and a more recently encoded material interfere and compete for conscious recall. A cue to forget the old material then supposedly reduces this material's interference by inhibiting it and thus improves recall of the new material. Similar to the inhibition concept in retrieval-induced forgetting, the inhibition concept in directed forgetting is silent about what exactly occurs when the old material is inhibited. We examined directed forgetting using response latency analysis (Bäuml et al., 2003). Like in retrieval-induced forgetting, the response latencies were consistent with the predictions of a weakening process, indicating that the forget cue reduces the strength of the bindings between inhibited items and their cue(s). As it seems, inhibition is realized in very similar ways in the two types of episodic forgetting.

Experiment 2 revealed further parallels between retrieval-induced forgetting and directed forgetting. In this experiment, we examined whether repeated testing can reduce, or even eliminate the inhibitory effects of retrieval practice and a forget cue. Previous work has shown that repeated testing often improves recall performance (Payne, 1987). Repeated testing provides new retrieval opportunities, may help re-instating the original learning context, and thus may help recalling previously not recalled material. The results of Experiment 2 showed the expected positive effects of repeated testing on recall performance, both in retrieval-induced forgetting and directed forgetting. However, in both types of forgetting, this positive effect was the same for inhibited and noninhibited items, indicating that repeated testing does not reduce the inhibitory effects.

The results of Experiment 2 also showed that there is no spontaneous recovery in directed forgetting. Previous work had demonstrated that retroactive interference effects are reduced if the interval between learning and test is increased (Wheeler, 1995). Our results indicate that the same is not true in directed forgetting. Because previous results showed that there is no spontaneous recovery in retrieval-induced forgetting as well (Bjork et al., 1998), our results point to another parallel between directed forgetting and retrieval-induced forgetting and another dissociation between interference on the one hand and retrieval-induced forgetting and directed forgetting on the other.

Experiment 3 examined the developmental course of the three forms of episodic forgetting. Using a proactive interference paradigm, we examined whether second graders, fourth graders, and adults differ in their interference susceptibility. Our results revealed clear interference effects in all three subject groups but did not show any differences in amount of interference across the three subject groups. The interference result parallels our finding on retrieval-induced forgetting. Indeed, we found no difference in the detrimental effects of retrieval practice on second graders', fourth graders', and adults' recall of unpracticed material (Zellner & Bäuml, 2003). By contrast, we found mature directed forgetting for adults and fourth graders but not for second graders (Zellner & Bäuml, 2003), thus replicating results from previous studies (Bray et al., 1983; Harnishfeger & Pope, 1996). Together these results suggest that interference and retrieval-induced forgetting, but not directed forgetting, are intact from at least second grade on, thus demonstrating a dissociation between retrieval-induced forgetting and directed forgetting.

Recent work points to further dissociations between retrieval-induced forgetting and directed forgetting. Retrieval-induced forgetting, for instance, can be demonstrated in both explicit and implicit memory tests, whereas directed forgetting is present in explicit tests only (Perfect, Moulin, Conway, & Perry, 2002). False recall of critical items in DRM lists (Roediger & McDermott, 1995) has been shown to be reduced in retrieval-induced forgetting (Bäuml & Kuhbandner, in press) but to be enhanced in directed forgetting (Kimball & Bjork, 2002). The parallels between retrieval-induced forgetting and directed forgetting suggest that inhibition is realized in very similar ways in the two forms of forgetting: in both cases inhibition results in the weakening of bindings between items and their cue(s). However, the dissociations between retrieval-induced forgetting and directed forgetting also indicate that the two forms of inhibition differ in the way in which inhibition is controlled, i.e., which factors induce such a weakening and which factors do not.

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

Following such two-stage models of recall, the question arises of whether episodic forgetting arises because an item is prevented from being sampled, or whether episodic forgetting arises because an item passes sampling but fails to be recovered. Our results suggest that retrieval inhibition, as it occurs both in retrieval-induced forgetting and directed forgetting, does not prevent inhibited items from being sampled. Rather, it reduces the absolute strength of inhibited items so that they can no longer be recovered. Retrieval inhibition thus is quite different from retrieval competition, as it occurs in retroactive and proactive interference, where the binding of additional material induces forgetting by increasing the competition between items. This increased competition leads to a reduction in the items' relative strength and lowers sampling chances. Retrieval competition, therefore, reflects a failure at the sampling stage of recall, whereas retrieval inhibition reflects a failure at the recovery stage.

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