How Retrieval Shapes Episodic Memories

Karl-Heinz Bäuml

1. Introduction

During his PhD years, Alf Zimmer worked on fundamental research in episodic memory, cumulating in his dissertation on the creation of order in human memory (Zimmer, 1973). Since then he kept up this interest in the field, although his focus shifted a bit from more fundamental to more applied issues in memory research. In particular, Alf Zimmer became interested in research on eyewitness testimony and, for instance, the question of how witnesses should be interrogated to extract as much information as possible from their memory representation of an observed incident. This is an important issue in applied memory research and so, like Alf Zimmer, a number of researchers got interested in this question in the 70-ies and 80-ies of the past century. The research led to the publication of a new technique to help police officers, and others, to interrogate witnesses efficiently. The technique was called the cognitive interview (Geiselman, Fisher, MacKinnon, & Holland, 1985).

The cognitive interview is based on four general retrieval mnemonics: (i) mentally reinstating a witness's internal and external context that occurred at the time the incident was observed, (ii) reporting every detail that comes to mind, regardless of how trivial or irrelevant it may appear, (iii) attempting to recount the incident in several different temporal orders, e.g., both forwards and backwards, (iv) attempting to report the incident from a range of different perspectives, e.g., the own perspective and that of other witnesses of the incident. Indeed, results from several studies showed that witnesses often show better recall of an observed incident when the cognitive interview was employed for interrogation than when so-called standard

techniques, as they have typically been used by police forces, were employed (e.g., Geiselman et al., 1985).
Part of the retrieval mnemonics used in the cognitive interview rely on the assumption that spreading activation is a core feature of human memory (e.g., Slamecka, 1968). The main idea of spreading activation is that, if one gets access to a particular memory entry, activation spreads out to related entries and thus enhances their chances for recall. This is a theoretical cornerstone of the cognitive interview, because in this technique witnesses are asked to recall every detail of an incident, regardless of how trivial or irrelevant it may appear, hoping that such detail helps recalling other, possibly more important aspects of the original event. It therefore came as an awkward surprise, when in the 70-ies researchers began to realize that often spreading activation processes are quite limited, or may not occur at all. Even worse, results from a number of studies indicated that recall of some previously studied material typically impairs, rather than improves, recall of the still-to-be retrieved material (e.g., Roediger, 1974; Smith, 1971). The finding was called output interference and led to the view that recall is a self-limiting process (Roediger, 1978).
At first glance surprising, output interference was not regarded a problem for the cognitive interview technique. The reason was that researchers in the 70-ies and 80-ies believed that output interference effects reflect transient blocking (Roediger, 1974; Rundus, 1973). There is abundant evidence that recall of material strengthens its representation in memory (Anderson, Bjork, & Bjork, 1994). Blocking then means that, during recall, the already recalled (stronger) material may come to mind persistently and, in this way, block access to the not-yet-recalled (weaker) material (e.g., Rundus, 1973). Because such blocking is not assumed to affect the memory representation of the not-recalled material, blocking effects were suggested to be transient and to go away if a different retrieval route to the target event was taken a few minutes later.
However, more recent research on so-called retrieval-induced forgetting indicates that retrieval may have much more powerful detrimental effects on not-yet-recalled information than researchers originally thought. Indeed, studies showed that repeated retrieval of a subset of previously studied material improves later recall of the retrieved material but often impairs recall of the nonretrieved material. In particular, the detrimental effect of re-

trieval turned out to be lasting and to reflect an impairment in the memory representation of the nonretrieved event itself (e.g., Anderson, 2003). Output interference effects, therefore, could constitute a problem for the cognitive interview. Moreover, because interviews of witnesses conducted by police officers or advocates often constitute incomplete retrieval tasks - a police officer may ask a witness about the color or brand of a car but not about whether the car showed any collision damage - there may be a detrimental effect of an witness's prior retrieval of information on details that were not the object of post-event interrogation.
The goal of the present contribution to this Festschrift is to review some of the main findings from the past 15 years on detrimental effects of retrieval, suggesting possible limitations of the cognitive interview and possible implications for eyewitness testimony research in general. Section 2 starts by introducing the basic experimental paradigm of retrieval-induced forgetting, the retrieval-practice paradigm; sections 3 and 4 show that the detrimental effects of retrieval are recall specific and that retrieval affects the memory representation of the nonretrieved material itself; sections 5 and 6 review representational preconditions for retrieval-induced forgetting and the role of emotion for this type of episodic forgetting; sections 7 and 8 then report on recent research on the neural correlates of retrieval-induced forgetting and the developmental trajectory of the effect; finally, section 9 will summarize the main results and offer some suggestions on the possible role of retrieval-induced forgetting for eyewitness testimony.

2. The Retrieval-Practice Paradigm

In 1994, a new experimental paradigm was introduced to study the detrimental effects of retrieval, the retrieval-practice paradigm (Anderson et al., 1994; Figure 1a). In this paradigm, individuals study items from different categories (e.g., Profession-*butcher*, Profession-*teacher*, Drink-*vodka*) and repeatedly retrieve half of the items from half of the categories in a subsequent retrieval practice phase (e.g., Profession-*bu*___). After a distractor task, subjects are asked to recall the originally studied items given the category names as retrieval cues. The typical finding in this paradigm is that, relative to control items from unpracticed categories (*vodka*), recall of prac-

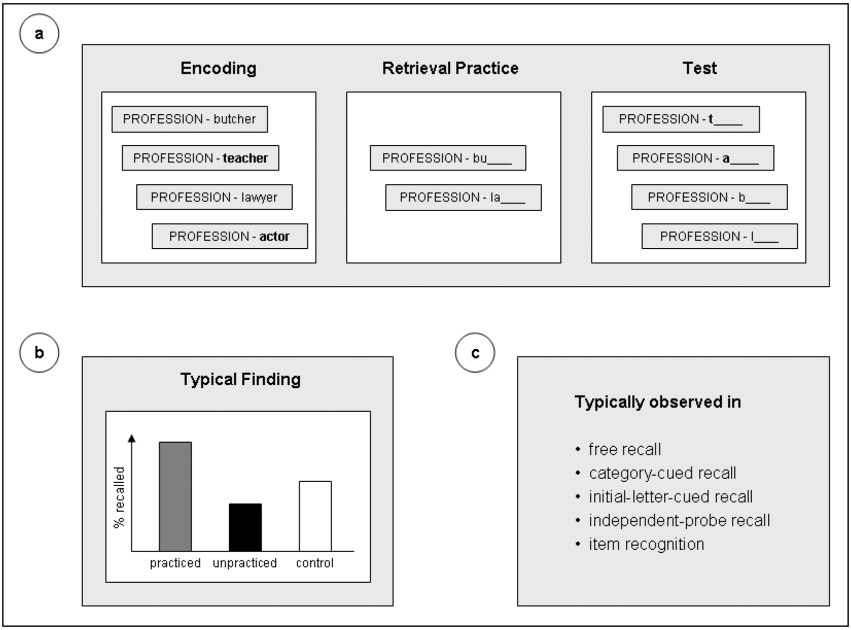

Fig. 1: Retrieval-induced forgetting. (a) The retrieval-practice paradigm. Participants study a categorized item list. In a subsequent retrieval-practice phase, half of the items from half of the studied categories are repeatedly retrieved. On the final test, participants are asked to recall all previously 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.

ticed exemplars (*butcher*) is enhanced and recall of unpracticed exemplars (teacher) is impaired (Figure 1b).

Retrieval-induced forgetting has been observed with a wide variety of stimulus classes. It has been found with verbal material (Anderson et al., 1994), visual material (Ciranni & Shimamura, 1999), and autobiographical material (Barnier, Hung, & Conway, 2004). It has proven relevant in a number of settings, such as fact learning (e.g., Anderson & Bell, 2001), memory for perceptual experiences (e.g., Schooler, Fiori, & Brandimonte,

1997), social cognition (e.g., Dunn & Spellman, 2003), and stereotype representations (e.g., Quinn, Hugenberg, & Bodenhausen, 2004).
In particular, retrieval-induced forgetting has been observed in a simulated legal context. Eyewitnesses to a crime typically are exposed to an abundance of questions intended to probe their memory for the incident under investigation. From immediately after the crime until a trial that may take place months later, an eyewitness may be interrogated, often repeatedly, by police officers, friends, other witnesses, lawyers, among others. Although such probing is usually a well-intentioned effort to get at the facts of what happened, prior work using the retrieval-practice paradigm suggested that interrogation may also induce detrimental memory effects.
Shaw, Bjork, and Handal (1995) thus examined the potential impact of repeated questioning of a witness on memories that originally were not subject to the interrogation. Subjects were shown slides depicting the aftermath of a theft and subsequently were asked several times to recall selected details of what they saw. Similar to what happened with other materials in the retrieval-practice paradigm, beneficial and detrimental effects of repeated interrogation appeared in subjects' later recall of crime-scene details, suggesting that, also in such simulated legal context, retrieval-induced forgetting may arise (for a related result, see MacLeod, 2002). Repeated interrogation of a witness thus may modify the witness's memory, enhancing the recall of certain details and reducing that of others.

3. Retrieval-Induced Forgetting as a Recall Specific Effect

When people in the 70-ies realized that recall can impair subsequent remembering of related material, they assumed that such forgetting is not retrieval specific. Indeed, any form of strengthening episodic material should cause this form of retrieval failure (Roediger, 1974; Rundus, 1973). Thus, the effects of retrieval - both the beneficial and the detrimental ones -, for instance, should mimic the effects of relearning, where subjects receive one or two additional study trials on a subset of previously presented material. However, research on retrieval-induced forgetting clearly indicated that the detrimental effects of retrieval are recall specific.

Anderson, Bjork, and Bjork (2000a) addressed the issue by letting subjects learn a categorized list (e.g., Fruit-*apple*, Fruit-*orange*). Then, subjects either retrieved a subset of a category's items given the word stem of the items as a retrieval cue (Fruit-*ap*___; competitive condition), or were provided the same items intact and were asked to recall the appropriate category name by using the exemplar and a stem as cues (Fr__-*apple*, noncompetitive condition). Although the two conditions led to comparable strengthening of the practiced items (*apple*), only the competitive condition but not the noncompetitive one induced forgetting of the nonstrengthened material (*orange*) on a final recall test. This finding indicates that retrieval-induced forgetting is not caused by the strengthening of competitors per se but rather is due to a recall-specific process.

Bäuml and Aslan (2004) compared the effects of retrieval practice and relearning directly. Subjects learned category exemplars consisting of target and nontarget items. In a subsequent phase, the nontarget items were reexposed for relearning or subjects were asked to retrieve the items in the presence of word stem cues. Relearning and retrieval occurred immediately before test or separated from test by a distractor task. The results showed that relearning has no detrimental effect on target material, replicating related prior work (e.g., Bäuml, 1996, 1997). By contrast, retrieval had detrimental effects on target recall (see Figure 2). Again, the finding suggests that retrieval-induced forgetting is not caused by the strengthening of related material per se but rather is due to a recall-specific process.

Bäuml (2002) provided further evidence for recall-specific processes in retrieval-induced forgetting by investigating a situation in which the retrieved and non-retrieved items are not part of the same experiential episode and task. Subjects learned a categorized list (e.g., Fruit-*apple*, Fruit-*orange*), which they were asked to recall later in the experiment. In a separate intermediate phase, they repeatedly generated related items from semantic memory (e.g., Fruit-*pine*___, Fruit-*ki*___), or were presented the same items intact for study (e.g., Fruit-*pineapple*, Fruit-*kiwi*). Only the semantic generation of items but not their presentation for study induced forgetting of the initially learned items. This result indicates that semantic generation can cause recall-specific episodic forgetting, thus generalizing the findings by Anderson et al. (2000a) and Bäuml and Aslan (2004) from episodic practice to semantic practice.

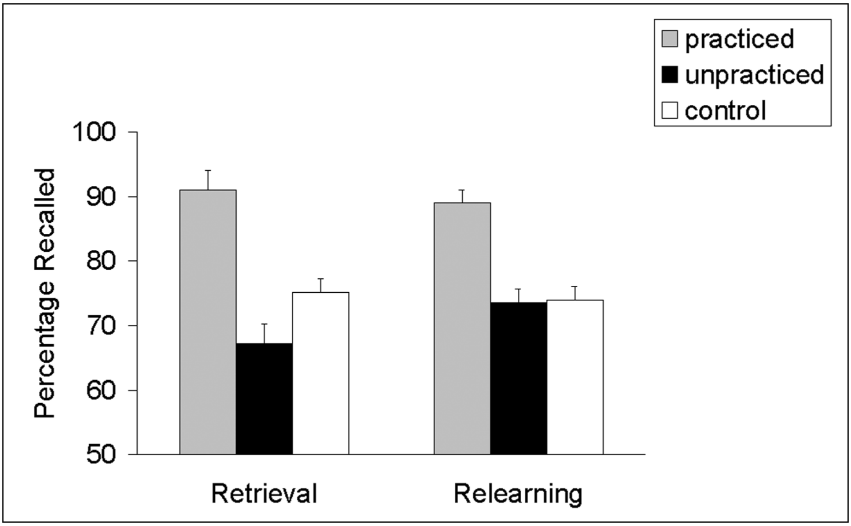

Fig. 2: Mean recall and standard errors on a category cued-recall test as a function of item type (practiced, unpracticed, control) and type of practice (retrieval, relearning). (K.-H. Bäuml & A. Aslan, Part-list cuing as instructed retrieval inhibition, Memory & Cognition, 32, 610-619, 2004, Psychonomic Society, Inc. Adapted with permission.)

4. Retrieval-Induced Forgetting as an Effect on Memory Representation

It is widely assumed that inhibition is the primary mechanism mediating retrieval-induced forgetting (see Anderson, 2003). The assumption is that during retrieval practice on a subset of studied material, related unpracticed items interfere and compete for conscious recall. To reduce the interference, the unpracticed material is inhibited, affecting the unpracticed items' memory representation (Anderson and Spellman, 1995). Due to the direct effect on the memory representation of the irrelevant information itself, such inhibition should be visible over a wide range of memory tests, including recognition tasks and tasks which employ so-called independent probes, i.e., probes not used until the test phase of an experiment.

Using the independent-probe procedure, Anderson and Spellman (1995) showed that retrieval-induced forgetting can be cue independent. Anderson and Spellman let subjects study lists consisting of items like Green-*emerald*, Green-*lettuce*, Soup-*mushroom*, and Soup-*minestrone*. The participants then repeatedly retrieved Green-*emerald* and thus caused forgetting of Green-*lettuce* on a later recall test. More important, the repeated retrieval of Green-*emerald* caused forgetting of Soup-*mushroom* as well, though not of Soup-*minestrone*. According to Anderson and Spellman, this finding suggests that, because *lettuce* and *mushroom* are vegetables and thus share a number of semantic features, the inhibition of *lettuce* spread to the representation of *mushroom* and thus impaired recall of Soup-*mushroom*. The fact that forgetting for *mushroom* arose although the cue at test (Soup) was different to the cue used in the retrieval-practice phase (Green) indicates that retrieval-induced forgetting suppresses an item's memory representation itself and, therefore, is cue independent (for a related result, see Anderson & Bell, 2001).

If retrieval-induced forgetting is mediated by impairments in the nonretrieved items' memory representation, retrieval-induced forgetting should also be present in item recognition tasks. 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*). Spitzer and Bäuml (2007) used different methods to measure subjects' recollective and familiarity processes in item recognition, among them the receiver operating characteristic (ROC) procedure (for details, see Yonelinas, 2002). They replicated the basic finding by Hicks and Starns (2004) that retrieval-induced forgetting is present in item recognition (see Figure 3). More important, when separating recognition performance into recollective and familiarity components (for underlying concepts and mathematical equations, see Spitzer & Bäuml, 2007), Spitzer and Bäuml found that retrieval practice does not only affect unpracticed items' recollection but reduces their familiarity as well, indicating that retrieval practice impairs the nonretrieved items' general memory representation (for a related result in a category recognition task, see Spitzer & Bäuml, 2009).

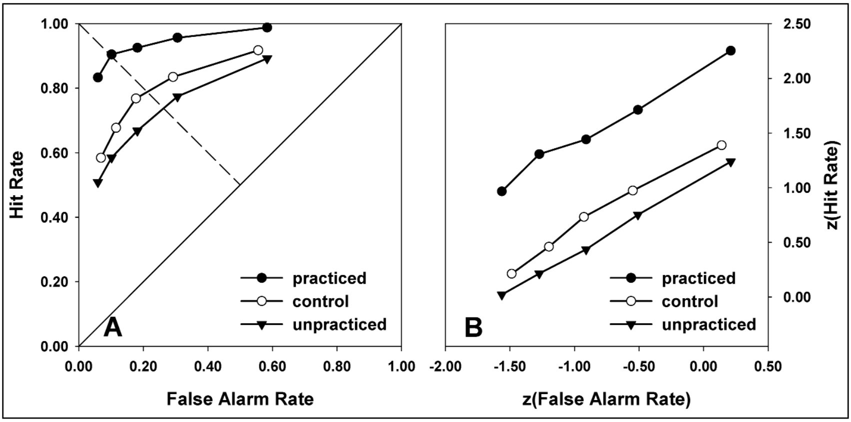

Fig. 3: Recognition receiver operating characteristics (ROCs) (A) and z-transformed ROCs (B) for practiced, unpracticed, and control items. (B. Spitzer & K.-H. Bäuml, Retrieval-induced forgetting in item recognition: evidence for a reduction in general memory strength, Journal of Experimental Psychology: Learning, Memory, and Cognition, 33, 863-875, 2007, American Psychological Association, Experiment 2. Adapted with permission.)

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 (e.g., Rohrer, 1996). 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. Exactly this should occur in retrieval-induced forgetting if the forgetting was mediated by inhibition. Fortunately, response latency analysis can be used to examine whether a change in recall performance is due to a change in sampling or a change in recovery. Indeed, if items are reduced in their absolute strength, then recall frequency of the items should decrease whereas response latency should be unaffected (e.g., Rohrer, 1996).

Bäuml, Zellner, and Vilimek (2005) measured recall frequencies and response latencies of retrieval-practiced and not retrieval-practiced items. They let participants study categorized lists with each category (e.g., Animals) consisting of exemplars from two different semantic subcategories (e.g., Predators, Hoofed Animals). In the retrieval-practice phase, subjects repeatedly retrieved the items from one of the two subcategories of a category, before, on the final test, they separately recalled the items from both subcategories. As expected, retrieval practice improved later recall of the practiced items (e.g., Predators) but impaired recall of the unpracticed items (e.g., Hoofed Animals). Most interestingly, besides the difference in recall rates, the two item types did not differ in response latencies from control items, as indicated by the fact that the three fitted exponentials did not differ in slope (see Figure 4). The finding is consistent with the view

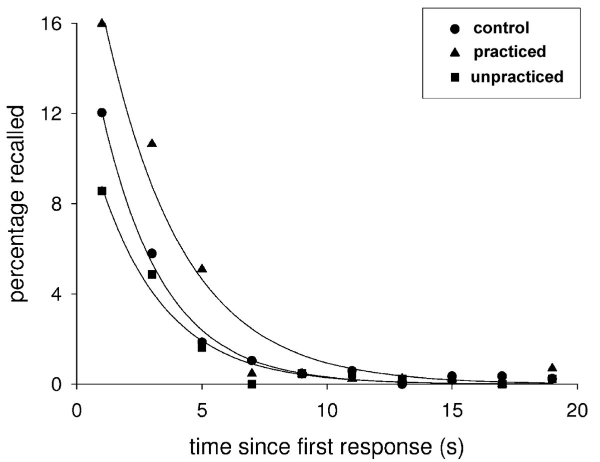

Fig. 4: Recall performance - percentage recalled - for each 2-sec bin of a 20-sec recall period for practiced, unpracticed, and control items together with the three best fitting exponentials. Latency is measured from the first response. (K.-H. Bäuml, M. Zellner, & R. Vilimek, When remembering causes forgetting: retrieval-induced forgetting as a recovery failure, Journal of Experimental Psychology: Learning, Memory, and Cognition, 31, 1221-1234, 2005, American Psychological Association, Experiment 2. Adapted with permission.)

that retrieval-induced forgetting is caused by inhibition which reduces the items' absolute memory strength. Thus, inhibited items may eventually be sampled but they may not exceed the recovery threshold.

5. Representational Preconditions of Retrieval-Induced Forgetting

Retrieval-induced forgetting arises only when practiced and unpracticed items share a common retrieval cue - be it contextual, semantic, or emotional in nature. Thus, if subjects study items from different semantic categories, like Fruit-*orange*, Fruit-*cherry*, and Insect-*bee*, retrieval practice on *orange* will lead to reduced memory performance for *cherry*, but will not affect performance of *bee*; indeed, bee, being connected to a different semantic cue than *cherry*, will show the same performance regardless of whether *orange* was previously practiced or not (Shaw et al., 1995).

In studies of the fan effect, Radvansky (1999) found less forgetting when participants integrated propositional knowledge into what he called location schemata. Similar results were obtained in studies of retrieval-induced forgetting. These studies show that retrieval-induced forgetting can be greatly reduced or even eliminated if participants enhance associations between practiced and unpracticed material. Anderson, Green, and McCulloch (2000b), for instance, showed that instructions to interrelate practiced (Animal-*tiger*) and unpracticed items (Animal-*horse*) in a meaningful way (Four-Legged Animal) can eliminate retrieval-induced forgetting. Similarly, Bäuml and Hartinger (2002) found that the use of strong pre-experimental associations between practiced (Animal-Carnivore-*tiger*) and unpracticed items (Animal-Carnivore-*lion*) can eliminate retrieval-induced forgetting.

These findings are also consistent with recent work employing Deese-Roediger-McDermott (DRM) lists (Deese, 1959; Roediger & McDermott, 1995). DRM lists consist of items, which are all strongly associated to a so-called critical item. When presented to participants, such lists can create high levels of false recall of the unstudied critical item. For instance, if participants study words like *pillow, bed, silence*, and so forth, all of which are the strongest semantic associates to the unpresented critical item, *sleep*, then they are highly likely to recall the critical item falsely. DRM lists differ substantially in the degree to which they cause false memories. Because this variation in false recall level is largely due to differences in the associations between the lists' critical item and the noncritical ones (Roediger, Watson, McDermott, & Gallo, 2001), high false recall lists should show more integration than low false recall lists and thus show less retrieval-induced forgetting.

Bäuml and Kuhbandner (2003) addressed the issue by running an experiment in which they examined the effect of retrieval practice on a subset of the items from DRM lists on recall of the lists' „critical" items. The critical items were part of the studied lists, thus addressing these items' veridical recall. As expected, retrieval practice induced an integration effect in the critical items' veridical recall, with substantial forgetting of critical items in lists with low false recall levels and no forgetting in lists with high false recall levels. These results are consistent with those from Anderson et al. (2000b) and Bäuml and Hartinger (2002) and indicate that integration can indeed eliminate retrieval-induced forgetting.

All of these findings are consistent with a refinement of the inhibition account, called feature suppression (Anderson & Spellman, 1995). Feature suppression assumes that items are represented as sets of features, and that, as a result of retrieval practice, both excitatory and inhibitory processes operate on these item features. The central assumption is that retrieval practice on an item activates those features of a nonretrieved target item that it shares with the practiced item, and suppresses those features of the nonretrieved target item that it does not share with the practiced item (see Figure 5). Thus, the model makes a clear-cut prediction on the role of item similarity in retrieval-induced forgetting: practice on an item (e.g., *lion*) should impair recall of those targets that are relatively dissimilar to the practiced item (e.g., *zebra*), but should not impair recall of targets that are highly similar to the practiced item (e.g., *tiger*). This follows because, compared to low-similar targets, a high-similar target should share a greater number of features with the practiced item, and thus should benefit more from the co-activation of its shared features and suffer less from the inhibition of its unique features. The experimental results reviewed above are consistent with this inhibitory model.

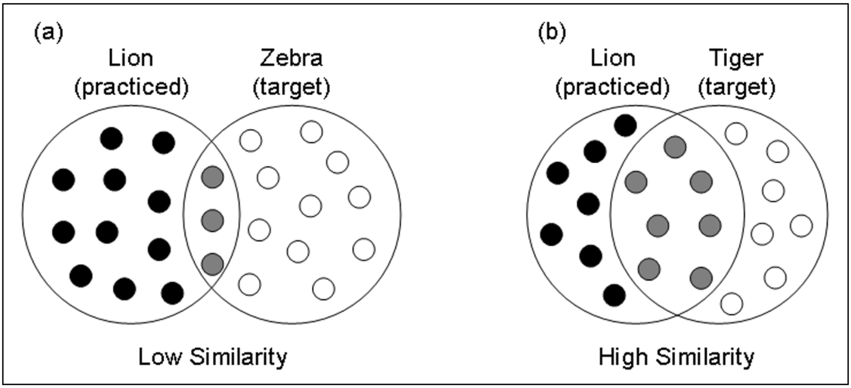

Fig. 5: Feature suppression model. Larger circles represent items, smaller circles represent item features. Retrieval practice on an item activates all of its features (small black and small grey circles); features that a target item shares with the practiced item are (co-)activated (small grey circles); features that a target item does not share with the practiced item are suppressed (small grey circles). (a) Low Similarity Condition: Zebra shares relatively few features with lion. Practicing the item lion thus (co-)activates few, but inhibits many features of the item zebra, causing significant forgetting. (b) High Similarity Condition: Tiger shares many features with lion. Practicing the item lion thus (co-)activates many, but inhibits few features of the item tiger, causing less forgetting, or no forgetting at all.

6. The Role of Emotion in Retrieval-Induced Forgetting

Prior research has shown that emotion guides cognitive processing and, in particular, can affect episodic memory (for a review, see Clore & Huntsinger, 2007). This influence is exerted at either a state-specific level, i.e., processing of emotionally neutral events in a specific affective state, or an item-specific level, i.e., processing of a specific emotional event in a neutral state. Thus, with respect to the role of emotion in retrieval-induced forgetting two related but separate questions arise. The first question is whether the affective state experienced during retrieval practice modulates the forgetting. The second question is whether the forgetting differs for emotional and nonemotional contents.

The question of whether retrieval-induced forgetting differs for emotional and nonemotional contents has recently been addressed in two studies, in which the emotional content of to-be-remembered words and self-generated autobiographical memories was varied (Amir et al., 2001; Barnier et al., 2004). In both studies reliable retrieval-induced forgetting arose for neutral material. More interesting, forgetting was present with emotional material as well, and the amount of forgetting was similar for emotional and nonemotional contents.

In a recent study, Kuhbandner, Bäuml, and Stiedl (in press) examined, in some detail, whether retrieval-induced forgetting holds also for negative material. Participants studied neutral and negative visual stimuli and then repeatedly retrieved a subset of the neutral material. Later, a recall test was conducted in which participants were asked to recall all previously studied items. On average, retrieval practice on the neutral items caused the same amount of forgetting for neutral and negative items, indicating that the emotionality of material does not affect retrieval-induced forgetting, which is consistent with the prior work. More detailed analysis, however, revealed that the forgetting of negative items decreased with both the emotional intensity of a negative item and the dispositional negative affectivity of a participant. The decreases in retrieval-induced forgetting may have been driven by item-specific processing of material, i.e., processing of items by their features and distinctive qualities (e.g., Hunt & McDaniel, 1993). Such processing is known to be enhanced for highly negative stimuli and participants high in dispositional negative affectivity (Clore & Huntsinger, 2007), and to reduce or even eliminate retrieval-induced forgetting (e.g., Anderson, 2003).

The question of whether the affective state experienced during retrieval practice modulates the forgetting has recently been addressed by Bäuml and Kuhbandner (2007). They examined how affective states experienced during retrieval modulate retrieval-induced forgetting by inducing positive, negative, and neutral moods immediately before the retrieval-practice phase. The results showed that repeated retrieval does not cause forgetting of nonretrieved items when participants are in negative moods; in contrast, when subjects are in positive or neutral moods, reliable forgetting arises (see Figure 6). The absence of retrieval-induced forgetting in negative moods is consistent with the view that negative moods induce predomi-

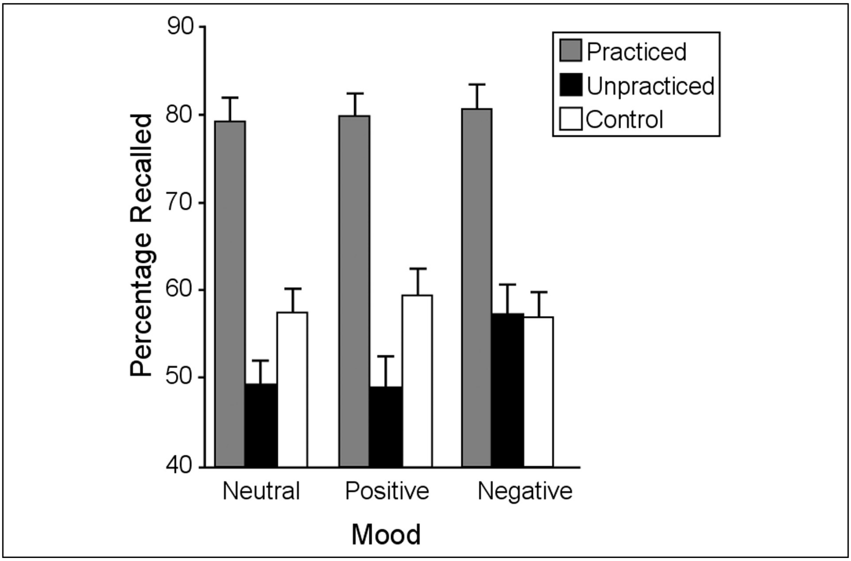

Fig. 6: Mean recall and standard errors on a category cued-recall test as a function of item type (practiced, unpracticed, control) and mood during retrieval practice (neutral, positive, negative). (K.-H. Bäuml & C. Kuhbandner, Remembering can cause forgetting - but not in negative moods. Psychological Science, 18, 111-115, 2007, Blackwell Publishing. Adapted with permission.)

nantly item-specific processing (e.g., Clore & Huntsinger, 2007). Because item-specific processing reduces interference from related information, inhibition should be reduced and retrieval-induced forgetting be eliminated, which is exactly what the data showed. It thus seems that mainly mood during retrieval and, to a lesser degree, emotional content of studied material affects retrieval-induced forgetting.

7. Neural Correlates of Retrieval-Induced Forgetting

Applying functional magnetic resonance imaging (fMRI), event-related potentials, and brain oscillations, several recent studies investigated the neural processes underlying retrieval-induced forgetting. Neural correlates of retrieval-induced forgetting were examined during the retrieval-practice phase and during the final memory test.

Because retrieval-induced forgetting is a recall-specific effect, two studies compared the neural activity elicited in a retrieval-practice condition (Fruit-*or*___) with activity in a relearning condition in which selective retrieval did not occur (Fruit-*orange*), thus isolating the putative inhibitory component (see Bäuml & Aslan, 2004). Using this rationale, Johansson, Aslan, Bäuml, Gäbel, and Mecklinger (2007) analyzed event-related brain potential (ERP) components in an electroencephalogram (EEG) study. The authors found an early onset and sustained increase in prefrontal ERP positivity during retrieval practice compared to relearning. Because prefrontal positivity was predictive of retrieval-induced forgetting, the activity was suggested to reflect the differential involvement of inhibition in retrieval as compared to relearning.

Wimber, Rutschmann, Greenlee, and Bäuml (2009) used fMRI to investigate the neural processes underlying retrieval-induced forgetting. Again, brain activity between a retrieval-practice and a relearning condition was compared. Selective retrieval was associated with increased brain activity in the hippocampus, the posterior temporal, parietal association cortices, and the dorsolateral prefrontal cortex (DLPFC). Again, the prefrontal brain activity was predictive of later retrieval-induced forgetting, albeit negative in direction. The authors suggested that the negativity of the correlation may be due to the repetition of retrieval-practice trials. According to this view, successful inhibition on early practice trials may reduce the need for inhibitory control on subsequent practice trials and thus exhibit an overall decrease of inhibition-related activation over the whole retrieval-practice phase.

Kuhl, Dudukovic, Kahn, and Wagner (2007) directly compared brain activity between a first and a third retrieval practice trial to test for decreases in inhibitory control demands. Consistent with the Wimber et al. (2009) interpretation, they found that repeated retrieval was accompanied by reduced brain activity in the anterior cingulate cortex (ACC) and the right lateral PFC. Prefrontal brain activity was predictive of later retrieval-induced forgetting which increased with reduced prefrontal activation across repeated retrieval attempts. Thus, the forgetting seems to be mediated by activations in anterior cingulate and lateral prefrontal activity, indicating interference and inhibition. This holds while effects were not restricted to prefrontal brain regions, but, like in the Wimber et al. (2009) study, a network of prefrontal, posterior, and medial-temporal regions including the hippocampus was found to be responsive to selective retrieval.

Concerning the effects of retrieval practice on the final memory test, two fMRI studies and one EEG study have been conducted to date. An fMRI study by Wimber, Bäuml, Bergström, Markopoulos, Heinze, and Richardson-Klavehn (2008) showed that retrieval-induced forgetting is reflected by an increase in left prefrontal brain activity. More precisely, the forgetting was specifically related to activation in the left anterior ventrolateral prefrontal cortex (VLPFC; but see Kuhl, Kahn, Dudukovic, & Wagner, 2008), a brain region that has been suggested to subserve selective retrieval of weakened memory representations stored in temporal regions (Badre & Wagner, 2007). Consistently, Wimber et al. observed a functional coupling of left anterior VLPFC with the posterior lateral temporal cortex. The finding that retrieval-induced forgetting is modulated by activity in these brain regions supports the view that forgetting reflects inhibition that directly affects the memory representation of unpracticed items.

Spitzer, Hanslmayr, Opitz, Mecklinger, and Bäuml (in press) examined the effects of prior retrieval practice on evoked ERPs and oscillatory power measures during a final recognition test. Whereas ERPs are phase-locked to stimulus onset, oscillatory power measures pick up dynamic changes of brain activity non-phase-locked to stimulus onset. Spitzer et al. found that retrieval-induced forgetting was characterized by reduced amplitudes of the P2 ERP component at frontal electrode sites, reduced theta power (4 to 7 Hz) at distributed sites, and reduced gamma power (60 to 85 Hz) at occipital sites. Because theta power has been suggested to reflect - amongst other things - items' memory strength and occipital gamma power the activation of sensory memory networks, these results suggest that retrieval-induced forgetting leads to a deactivation of items' memory representations and a weakening of the material's sensory representation, as is predicted by the inhibitory account of retrieval-induced forgetting.

8. Developmental Trajectory of Retrieval-Induced Forgetting

The role of inhibition in cognition is of central interest in the literature on cognitive development. Partly this is due to findings reporting poor performance of young children and older adults in a number of inhibition tasks (e.g., Hartman & Hasher, 1991). In particular, it is due to the hypothesis that young children and older adults suffer from a general deficit in inhibitory function (Bjorklund & Harnishfeger, 1990; Hasher & Zacks, 1988). Such a general deficit in inhibitory function might also apply to memory and be at the heart of the reduced memory performance of young children and older adults. The hypothesis of a general inhibitory deficit in young children and older adults suggests that the two age groups show reduced retrieval-induced forgetting as a result of deficient inhibitory function.

Only few studies exist to date in which retrieval-induced forgetting was studied in older adults. In a nondevelopmental study, Moulin, Perfect, Conway, North, Jones, and James (2002) found retrieval-induced forgetting in Alzheimer 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, Bäuml, and Pastötter (2007) examined retrieval-induced forgetting in younger and older adults and found equivalent amounts of 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, retrieval-induced forgetting is reflected in an effect on the items' memory representation itself.

In children, retrieval-induced forgetting has mainly been studied using cued recall tasks at test. Zellner and Bäuml (2005), for instance, 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 amount of forgetting across participant groups, suggesting that in-

hibition was effective in young children. Analogous results were reported by Lechuga, Moreno, Pelegrina, Gomez-Ariza, and Bajo (2006), who examined retrieval-induced forgetting in 8- and 12-year-old children.
More recently, however, Aslan and Bäuml (2009) examined the effects of retrieval practice in kindergartners, second graders, and young adults using both a category-cued recall task and an old/new recognition test. While the three age groups showed equivalent retrieval induced forgetting (RIF) in recall, only second graders and adults, but not kindergartners, showed retrieval-induced forgetting in recognition. Because recognition tests provide a more sensible measure of inhibitory effects than cued recall tasks (see Anderson, 2003, or Spitzer & Bäuml, 2007), the recognition finding supports the inhibition-deficit hypothesis and suggests that remarkable progress in inhibitory function occurs around the time of school entry. The finding of retrieval-induced forgetting in kindergartners' recall is attributed to blocking at test, reflecting the tendency of kindergartners to perseverate on strong (previously retrieved) items at the expense of weak (previously non-retrieved) items, thus causing retrieval-induced forgetting without inhibition. The results thus support the view of a general inhibitory deficit in young children but reject the view of a general inhibitory deficit in older adults (for a discussion, see Aslan et al., 2007).

9. Summary and Suggestions

The results from numerous studies of the past 15 years demonstrate that the retrieval of episodic material can have detrimental effects on later recall of related material. The finding has been shown for a wide range of stimulus materials and a wide range of experimental settings. Moreover, retrieval-induced forgetting is a recall-specific phenomenon. Accordingly, it is not the retrieval-induced strengthening of the practiced material per se which is responsible for the forgetting, but rather it is the *recall* of the material, which creates the effect. Equally remarkable, retrieval-induced forgetting is present over a wide range of memory tests, including cued recall, recognition, and independent-probe testing, indicating that the forgetting reflects an effect on the memory representation of the unpracticed material itself.
All of these results agree with the view that inhibition is the primary mech-

anism mediating retrieval-induced forgetting. The assumption is that during retrieval practice on a subset of studied material, related unpracticed items interfere and compete for conscious recall. To reduce the interference, the unpracticed material is inhibited, leading to an impairment in the unpracticed items' memory representation. The finding of retrieval-induced forgetting in recognition and independent-probe tests supports this view, because effects on the items' memory representation should be visible mainly in recognition tasks and tests employing the cue-independence technique.

The findings on the neural correlates of retrieval-induced forgetting are consistent with the inhibitory account of retrieval-induced forgetting. They suggest that, during retrieval practice, the anterior cingulate cortex detects interference from unpracticed material, and the dorsolateral prefrontal cortex and ventro-lateral prefrontal cortex resolve the conflict by strengthening the practiced memories and inhibiting the unpracticed memories. At test, reduced electrophysiological activity and an increase in BOLD signal in the left anterior ventro-lateral prefrontal cortex were found for the unpracticed material, suggesting that the memory signal of the unpracticed material is impaired as a result of the prior retrieval practice. Together, the findings fit nicely with the view that retrieval practice affects the memory representation of related, unpracticed material.

If retrieval practice triggers inhibitory control mechanisms, which resolve interference, retrieval-induced forgetting should not be present in young children. The reason is that cognitive control functions are typically late in development and may even take until the end of the elementary school days to develop fully (e.g., Bjorklund & Harnishfeger, 1990). Although previous research first of all provided evidence for intact retrieval-induced forgetting in young children, when using more inhibition-sensible memory tests, like recognition tests, recent research showed that retrieval-induced inhibition is not yet present in young children. The finding agrees with the proposal that young children show a general inhibitory deficit, and thus supports the view that retrieval-induced forgetting is caused by inhibitory control mechanisms.

Retrieval-induced forgetting is a remarkably robust finding. Accordingly, to date only few marginal conditions for this form of episodic forgetting have been established. The one marginal condition refers to the encoding stage of the retrieval-practice paradigm and indicates that a high degree of integration between practiced and unpracticed material can eliminate the forgetting. Evidence for such integration effects arose from studies using both episodic and semantic integration manipulations. The other marginal condition refers to the retrieval-practice phase of the paradigm and indicates that negative moods during retrieval can eliminate the forgetting. Evidence for such an effect arose when negative moods were induced immediately before the start of the retrieval-practice phase. Supposedly, negative moods reduce interference from related material and thus eliminate the forgetting.

While retrieval-induced forgetting is of theoretical significance for our understanding of episodic memory, it is also of interest for applied issues, like, for instance, research on eyewitness testimony. Using a simulated legal context, in recent years several studies examined whether retrieval-induced forgetting may also arise in an experimental eyewitness setting. Consistent across the studies, evidence was reported that selective questioning on an observed incident can impair the later recall of details that were not the object of questioning. These studies add to the growing body of research demonstrating that simple, direct questioning of a witness, even in the absence of any misleading or inconsistent information, can alter what is recallable in later memory tests.

The finding of retrieval-induced forgetting may also be of relevance for the cognitive interview. In this technique, it is, for instance, suggested that witnesses report every detail that comes to mind, regardless of how trivial or irrelevant it may appear. If retrieval can cause forgetting of related material, recalling every detail that comes to mind may actually impair rather than improve recall of the remaining, potentially important information. It thus might be that the retrieval mnemonics underlying the cognitive interview undermine a witness's successful retrieval of information.

Of course, as pointed out in more detail by Shaw et al. (1995), one must be cautious in generalizing findings from the laboratory to real-life situations and real-world eyewitnesses, because some principal differences exist between the experiences of subjects in typical experiments on retrieval-induced forgetting and the typical experiences of witnesses to, for instance, actual crimes. Indeed, calmly viewing pictures or words in an experiment on retrieval-induced forgetting in the laboratory is clearly different from witnessing a real crime in progress. Also, subjects in retrieval-induced forgetting experiments are typically warned before the experiment that their memory on the observed material will be tested at the end of the experiment, whereas eyewitnesses typically do not receive such forewarning. Finally, whereas eyewitnesses may have to wait many months before testifying in court, the elapsed time between study and test in typical retrieval-induced forgetting experiments is less than 30 min.

While, arguably, there may be no a priori reason to expect that real-world questioning would produce a pattern of effects different from that observed in typical retrieval-induced forgetting experiments (for a discussion, see Shaw et al., 1995), the question of exactly how long the detrimental effects of retrieval practice last appears crucial for their potential relevance for applied issues. Unfortunately, the issue is not yet solved. Whereas the results from some studies suggest that the retrieval-induced forgetting effect is relatively short-lived and may already be gone after a single day (MacLeod & Macrae, 2001), more recent research indicates that the effect may last for at least a week (Garcia-Bajos, Migueles, & Anderson, in press). It is a high priority for future work to determine how lasting retrieval-induced forgetting actually is. Providing an answer on this question will bring us closer to an evaluation of which implications research on retrieval-induced forgetting may bear for actual eyewitness settings.

References

Amir, N., Coles, M.E., Brigidi, B. & Foa, E.B. (2001). The effect of practice on recall of emotional information in individuals with generalized social phobia. Journal of Abnormal Psychology, 110, 76-82.

Anderson, M.C. (2003). Rethinking interference theory: executive control and the mechanisms of forgetting. Journal of Memory and Language, 49, 415-445.

Anderson, M.C. & Bell, T. (2001). Forgetting our facts: the role of inhibitory processes in the loss of propositional knowledge. Journal of Experimental Psychology: General, 130, 544-570.

Anderson, M.C., Bjork, E.L. & Bjork, R.A. (2000a). Retrieval-induced forgetting: evidence for a recall-specific mechanism. Psychonomic Bulletin & Review, 7, 522-530.

Anderson, M.C., Bjork, R.A. & Bjork, E.L. (1994). Remembering can cause forgetting: retrieval dynamics in long-term memory. Journal of Experimental Psychology: Learning, Memory, and Cognition, 20, 1063-1087.

Anderson, M.C., Green, C. & McCulloch, K.C. (2000b). Similarity and inhibition in long-term memory: evidence for a two-factor theory. Journal of Experimental Psychology: Learning, Memory, and Cognition, 26, 1141-1159.

Anderson, M.C. & Spellman, B.A. (1995). On the status of inhibitory mechanisms in cognition: memory retrieval as a model case. Psychological Review, 102, 68-100.

Aslan, A. & Bäuml, K.-H. (2009). Memory control in young children – a deficit in inhibitory executive function. Unpublished Manuscript, Regensburg University, Germany.

Aslan, A., Bäuml, K.-H. & Pastötter, B. (2007). No inhibitory deficit in older adults' episodic memory. Psychological Science, 18, 72-78.

Badre, D. & Wagner, A.D. (2007). Left prefrontal cortex and the cognitive control of memory. Neuropsychologia, 45, 2883-2901.

Barnier, A.J., Hung, L. & Conway, M.A. (2004). Retrieval-induced forgetting of emotional and unemotional autobiographical memories. Cognition and Emotion, 18, 457-477.

Bäuml, K.-H. (1996). Revisiting an old issue: retroactive interference as a function of the degree of original and interpolated learning. Psychonomic Bulletin & Review, 3, 380-384.

Bäuml, K.-H. (1997). The list-strength effect: strength-dependent competition or suppression? Psychonomic Bulletin & Review, 4, 260-264.

Bäuml, K.-H. (2002). Semantic generation can cause episodic forgetting. Psychological Science, 13, 357-361.

Bäuml, K.-H. & Aslan, A. (2004). Part-list cuing as instructed retrieval inhibition. Memory & Cognition, 32, 610-617.

Bäuml, K.-H. & Hartinger, A. (2002). On the role of item similarity in retrieval-induced forgetting. Memory, 10, 215-224.

Bäuml, K.-H. & Kuhbandner, C. (2003). Retrieval-induced forgetting and part-list cuing in associatively structured lists. Memory & Cognition, 31, 1188-1197.

Bäuml, K.-H. & Kuhbandner, C. (2007). Remembering can cause forgetting - but not in negative moods. Psychological Science, 18, 111-115.

Bäuml, K.-H., Zellner, M. & Vilimek, R. (2005). When remembering causes forgetting: retrieval-induced forgetting as recovery failure. Journal of Experimental Psychology: Learning, Memory, and Cognition, 31, 1221-1234.

Bjorklund, D.F. & Harnishfeger, K.K. (1990). The resources construct in cognitive development: Diverse sources of evidence and a theory of inefficient inhibition. Developmental Review, 10, 48-71.

Ciranni, M.A. & Shimamura, A.P. (1999). Retrieval-induced forgetting in episodic memory. Journal of Experimental Psychology: Learning, Memory, and Cognition, 25, 1403-1414.

Clore, G.L. & Huntsinger, J.R. (2007). How emotions inform judgment and regulate thought. Trends in Cognitive Science, 11, 393-399.

Deese, J. (1959). On the prediction of occurence of particular verbal intrusions in immediate recall. Journal of Experimental Psychology, 58, 17-22.

Dunn, J.C. & Spellman, B.A. (2003). Forgetting by remembering: Stereotype inhibition through rehearsal of alternative aspects of identity. Journal of Experimental Social Psychology, 39, 420-433.

Garcia-Bajos, E., Migueles, M. & Anderson, M.C. (in press). Script knowledge modulates retrieval-induced forgetting for eyewitness events. Memory.

Geiselman, R.E., Fisher, R.P., MacKinnon, D.P, & Holland, H.L. (1985). Eyewitness memory enhancement in the police interview: cognitive retrieval mnemonics versus hypnosis. Journal of Applied Psychology, 70, 401-412.

Hartman, M. & Hasher, L. (1991). Aging and suppression: memory for previously relevant information. Psychology & Aging, 6, 587-594.

Hasher, L. & Zacks, R.T. (1988). Working memory, comprehension, and aging: a review and a new view. In G.H. Bower (Ed.), The psychology of learning and motivation: Advances in research and theory (Vol. 22, pp. 193-225). San Diego: Academic Press.

Hicks, J.L. & Starns, J. (2004). Retrieval-induced forgetting occurs in tests of item recognition. Psychonomic Bulletin & Review, 11, 125-130.

Hunt, R. & McDaniel, M. (1993). The enigma of organization and distinctiveness. Journal of Memory and Language, 32, 421-445.

Johansson, M., Aslan, A., Bäuml, K.-H., Gäbel, A. & Mecklinger, A. (2007). When remembering causes forgetting: electrophysiological correlates of retrieval-induced forgetting. Cerebral Cortex, 17, 1335-1341.

Kuhbandner, C., Bäuml, K.-H. & Stiedl, F.C. (in press). Retrieval-induced forgetting of negative stimuli: the role of emotional intensity. Cognition and Emotion.

Kuhl, B.A., Dudukovic, N.M., Kahn, I. & Wagner, A.D. (2007). Decreased demands on cognitive control reveal the neural processing benefits of forgetting. Nature Neuroscience, 10, 908-914.

Kuhl, B.A., Kahn, I., Dudukovic, N.M. & Wagner, A.D. (2008). Overcoming suppression in order to remember: Contributions from anterior cingulated and

ventrolateral prefrontal cortex. Cognitive and Affective Behavioral Neuroscience, 8, 211-221.
Lechuga, M.A, Moreno, V., Pelegrina, S., Gomez-Ariza, C.J. & Bajo, M.T. (2006). Age differences in memory control: evidence from updating and retrieval-practice tasks. Acta Psychologica, 123, 279-298.
MacLeod, M.D. (2002). Retrieval-induced forgetting in eyewitness memory. Forgetting as a consequence of remembering. Applied Cognitive Psychology, 16, 135-149.
MacLeod, M.D. & Macrae, C.N. (2001). Gone but not forgotten: the transient nature of retrieval-induced forgetting. Psychological Science, 12, 148-152.
Moulin, C.J.A., Perfect, T.J., Conway, M.A., North, A., Jones, R.W. & James, A.N. (2002). Retrieval-induced forgetting in Alzheimer's disease. Neuropsychologia, 40, 862-867.
Quinn, K. A., Hugenberg, K. & Bodenhausen, G. V. (2004). Functional modularity in stereotype representation. Journal of Experimental Social Psychology, 40, 519-527.
Radvansky, G.A. (1999). Memory retrieval and suppression: the inhibition of situation models. Journal of Experimental Psychology: General, 128, 563-579.
Roediger, H.L. III (1974). Inhibiting effects of recall. Memory & Cognition, 2, 261-269.
Roediger, H.L. III (1978). Recall as a self-limiting process. Memory & Cognition, 6, 54-63.
Roediger, H.L. III & McDermott, K.B. (1995). Creating false memories: Remembering words not presented in lists. Journal of Experimental Psychology: Learning, Memory, and Cognition, 21, 803-814.
Roediger, H.L. III, Watson, J.M., McDermott, K.B. & Gallo, D.A. (2001). Factors that determine false recall: a multiple regression analysis. Psychonomic Bulletin & Review, 8, 385-407.
Rohrer, D. (1996). On the relative and absolute strength of a memory trace. Memory & Cognition, 24, 188-201.
Rundus, D. (1973). Negative effects of using list items as recall cues. Journal of Verbal Learning and Verbal Behavior, 12, 43-50.
Schooler, J.W., Fiore, S.M. & Brandimonte, M.A. (1997). At a loss from words: Verbal overshadowing of perceptual memoris. In D.L. Medin (Ed.), The psychology of learning and motivation: Advances in research and theory (Vol. 37, pp. 291-340). San Diego, CA: Academic Press.
Shaw, J.S. III, Bjork, R.A. & Handal, A. (1995). Retrieval-induced forgetting in an eyewitness-memory paradigm. Psychonomic Bulletin & Review, 2, 249-253.

Slamecka, N.J. (1968). An examination of trace storage in free recall. Journal of Experimental Psychology, 76, 504-513.

Smith, A.D. (1971). Output interference and organized recall from long-term memory. Journal of Verbal Learning and Verbal Behavior, 10, 400-408.

Spitzer, B. & Bäuml, K.-H. (2007). Retrieval-induced forgetting in item recognition: evidence for a reduction in general memory strength. Journal of Experimental Psychology: Learning, Memory, and Cogntion, 33, 863-875.

Spitzer, B. & Bäuml, K.-H. (2009). Retrieval-induced forgetting in a category recognition task. Journal of Experimental Psychology: Learning, Memory, and Cogntion, 35, 286-291.

Spitzer, B., Hanslmayr, S., Opitz, B., Mecklinger, A. & Bäuml, K.-H. (in press). Oscillatory correlates of retrieval-induced forgetting in recognition memory. Journal of Cognitive Neuroscience.

Tulving, E. (1985). Memory and consciousness. Canadian Psychology, 26, 1-12.

Wimber, M., Bäuml, K.-H., Bergström, Z., Markopoulos, G., Heinze, H.-J. & Richardson-Klavehn, A. (2008). Neural markers of inhibition in human memory retrieval. Journal of Neuroscience, 28, 13419-13427.

Wimber, M., Rutschmann, R.M., Greenlee, M.W. & Bäuml, K.-H. (2009). Retrieval from episodic memory: Neural mechanisms of interference resolution. Journal of Cognitive Neuroscience, 21, 538-549.

Yonelinas, A.P. (2002). The nature of recollection and familiarity: a review of 30 years of research. Journal of Memory and Language, 46, 441-517.

Zellner, M. & Bäuml, K.-H. (2005). Intact retrieval inhibition in children's episodic recall. Memory & Cognition 33, 396-404.

Zimmer, A.C. (1973). Die Bildung von Ordnungen im menschlichen Gedächtnis. Unpublished dissertation, University of Münster, Germany.