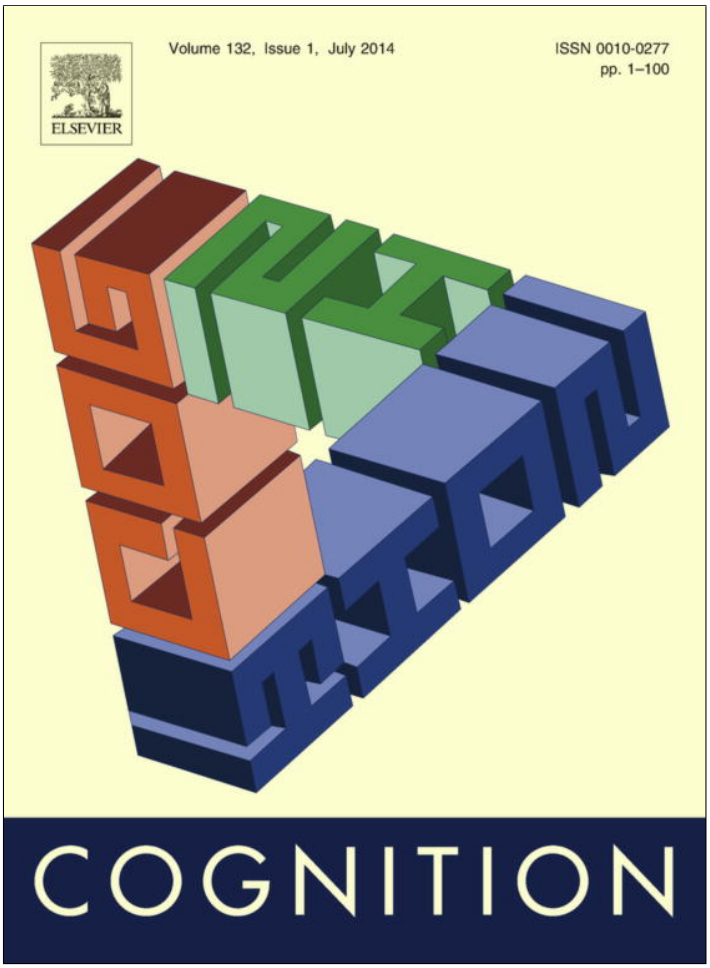

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Brief article

Memory retrieval as a self-propagating process

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ABSTRACT

Retrieval of a subset of studied items and the presentation of those items as retrieval cues typically impair retrieval of the other items. Previous research on this self-limiting property of memory retrieval has relied heavily on short retention intervals and similar context between encoding and test. Here, we examined retrieval dynamics also after a prolonged retention interval with different spatial and social context between encoding and test, conditions that mimic people's remembering in many situations of daily life. For both unrelated word lists and more integrated prose material, we found retrieval and cuing to impair recall of other studied items after a short retention interval, but to improve recall in the prolonged retention interval condition. The results demonstrate that retrieval dynamics depend critically on situation, indicating that quite often in daily life, retrieval may be a self-propagating, rather than a self-limiting process.

1. Introduction

When we try to retrieve details of a previous event, like yesterday's birthday party of a friend, a crime that we incidentally observed a week ago, or a recent summer vacation, does retrieval of some first details affect retrieval of the other details? Results from numerous studies of the past decades suggest possible detrimental effects of such initial retrieval processes, indicating that retrieval can induce forgetting. For instance, studies employing the retrieval-practice task (Anderson, Bjork, & Bjork, 1994; Anderson & Spellman, 1995) and the output-interference task (Roediger, 1974; Smith, 1971) have shown that recall of some studied items typically impairs subsequent recall of the other items. Similarly, studies employing the part-set cuing task have demonstrated that the presence of some studied items as retrieval cues can reduce recall of the remaining items (Roediger, 1973; Slamecka, 1968). The findings have led to the conceptualization of retrieval as a self-limiting process, according to which the initial retrieval inhibits or blocks the retrieval of the other information (Anderson, 2003; Roediger & Neely, 1982). Because cuing may lead people to covertly retrieve the cue items, the effects of retrieval and cuing have been regarded equivalent (Anderson et al., 1994; Roediger, 1973).

Most previous research on retrieval-induced forgetting was conducted under conditions that differ strikingly from people's typical remembering in daily life. The research employed time intervals between encoding and test of few minutes only, there were no changes in spatial or social environment between the two points in time, and there were at best minimal changes in people's internal states. In contrast, remembering in daily life often takes place after prolonged time intervals; it may occur at a different spatial location than the encoding of the event; different persons may be around at recall than were present during encoding; and people's internal (physiological and psychological) states may have changed after encoding. Whether (covert) retrieval inhibits or blocks the subsequent retrieval of other information under such conditions

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is unclear, although results from some recent studies suggest that retrieval may no longer be self-limiting after prolonged retention interval.

Bäuml and Samenieh (2012a, 2012b) examined the effects of (covert) retrieval in a variant of the two-list context-change paradigm employing a short retention interval (e.g., Sahakyan & Kelley, 2002). Subjects studied two lists of items and, between study of the two lists, changed their internal context by means of an imagination task. After study of the second list, subjects' memory for predefined target items of the first list was tested. Target recall was preceded by retrieval of the list's remaining (nontarget) items, or the nontarget items were provided as retrieval cues for recall of the target items; as a control, target items were tested only, in the absence of the nontarget items. The results showed typical retrieval-induced forgetting and part-set cuing impairment in the absence of the imagination task, but showed beneficial effects of retrieval and cuing in its presence, thus indicating that contextual change between encoding and test can influence retrieval dynamics and create beneficial effects of retrieval processes.

The finding that changes in context between encoding and test can induce beneficial effects of retrieval processes suggests that after prolonged retention intervals, in which often a considerable amount of external and internal contextual change arises, retrieval may also be self-propagating. We examined the suggestion in three experiments, in which we compared the effects of retrieval and cuing across two retention conditions. Experiments 1 and 3 used unrelated word lists, Experiment 2 more integrated prose material. In all three experiments, participants studied predefined target and nontarget items, which were determined by the experimenter but were unknown to the participants. After a retention interval of few minutes, during which spatial and social context were left unchanged, participants in the short retention interval condition recalled the target items under one of three conditions. In the *prior retrieval condition*, participants recalled the target items after prior selective recall of the nontarget items; in the *cuing condition*, the nontarget items were provided as retrieval cues for participants' recall of the target items; in the *control condition*, participants recalled the target items only, in the absence of the nontarget items. The same three conditions were employed in the long retention interval condition. In this condition, however, there was an interval of 48 h between study and test, study and test were conducted at different spatial locations, and different experimenters attended the participants during the study and test sessions of the experiment, thus simulating conditions as they are often met in daily life.

We expected different results in the two retention interval conditions. Following classic work on retrieval-induced forgetting and part-set cuing impairment (Anderson, 2003; Roediger & Neely, 1982), we expected the typical detrimental effects of retrieval and cuing on recall of the target items after the short retention interval. In contrast, following more recent work on the role of contextual change for retrieval processes (Bäuml & Samenieh, 2012a, 2012b), we expected beneficial effects of retrieval and cuing on target recall after the long retention interval. Such pattern would support the view of the two faces of memory retrieval (Bäuml & Samenieh, 2010) and indicate that quite often in daily life, retrieval may be self-propagating, rather than self-limiting.

2. Experiment 1

2.1. Method

2.1.1. Participants

144 undergraduates took part in the study ($M = 22.0$ years, range = 18–32 years). They received monetary reward for participation.

2.1.2. Materials

Two study lists were constructed, each containing 15 unrelated concrete German nouns (e.g., Bäuml & Samenieh, 2010). Each participant studied one of the lists. The lists consisted of 5 target and 10 nontarget items each. Each target in a list had a unique initial letter; the nontargets began with unique word stems.

2.1.3. Design

The experiment had a 2×3 design with the between-participants factors of retention interval (short, long) and retrieval condition (prior retrieval, cuing, control). Participants were tested on the study list 4 min after study (short interval) or after an interval of 48 h (long interval). At test, participants were either asked to recall the nontargets first and the targets second (prior retrieval condition), recall the targets in the presence of the nontargets serving as cues (cuing condition), or recall the targets only, in the absence of the nontarget items (control condition). Assignment of lists to conditions was counterbalanced.

2.1.4. Procedure

For participants in the short, but not the long retention interval condition, study and test were conducted by the same experimenter in the same room. Participants in the long retention interval condition who studied the list in the presence of a female experimenter were tested by a male experimenter (and vice versa); participants who studied in a bright lab on the first floor of the department took the test in a basement lab of very different appearance (and vice versa). Items were studied individually and in a random order for 5 s each. Both before and after list presentation, all participants took part in a 4-min distractor task, rating faces according to their perceived sympathy before study, and solving arithmetical problems after study. At test, in all three retrieval conditions, the targets' initial letters were presented successively and in a random order, for 6 s each, and participants were asked to recall the appropriate items from the original study list. In the prior retrieval condition, nontargets were tested previously, providing the items' word stems as cues; the stems were presented successively and in a random order, for 6 s each. In the cuing condition, the nontargets were presented in two randomly ordered columns of 5 items; participants were asked to read the items aloud and use them as cues for recall of the remaining items; the nontargets remained

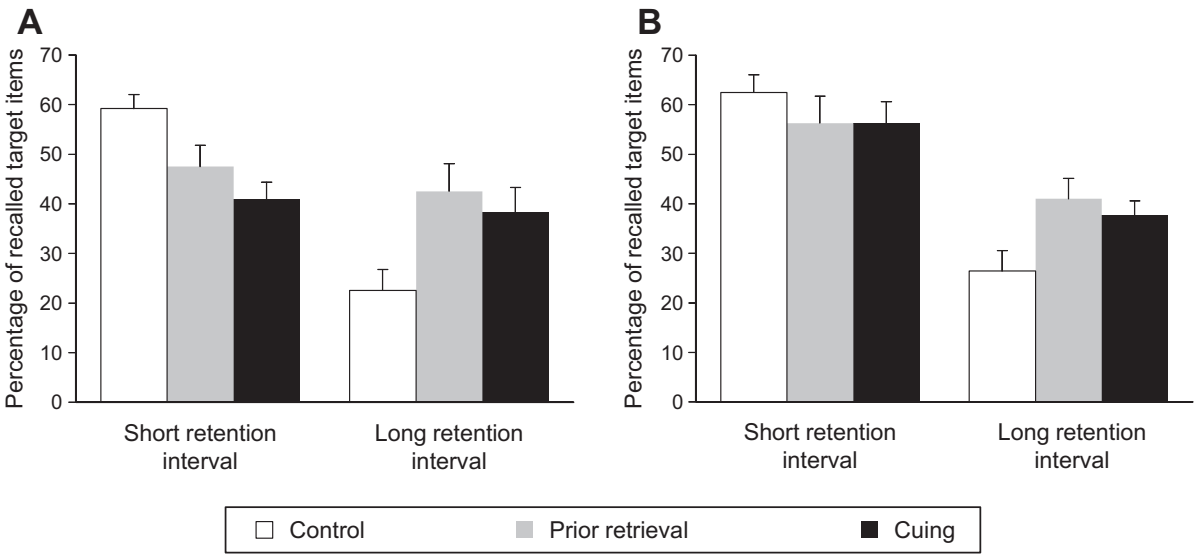

Fig. 1. Results of Experiment 1 (A) and Experiment 2 (B). Mean recall rates for predefined target items are shown as a function of retention interval (short, long) and retrieval condition (control, prior retrieval, cuing). Error bars represent standard errors.

present during target recall. In all conditions, responses were given orally (see Bäuml & Samenieh, 2012a, 2012b).

2.2. Results and discussion

Fig. 1 shows target recall rates. Target recall was lower after the long retention interval than after the short retention interval when target items were tested first (59.2% vs. 22.5%), $t(46) = 7.22$, $p < .001$, $d = 2.08$, thus revealing typical time-dependent forgetting. More important, retention interval affected retrieval dynamics. Whereas prior nontarget recall impaired memory for targets in the short retention interval condition (59.2% vs. 47.5%), $t(46) = 2.27$, $p = .028$, $d = .65$, it improved memory after the long retention interval (22.5% vs. 42.5%), $t(46) = 2.87$, $p = .006$, $d = .83$. Similarly, whereas presentation of the nontargets as cues impaired memory for targets after the short retention interval (59.2% vs. 40.8%), $t(46) = 4.08$, $p < .001$, $d = 1.18$, it improved memory in the long retention interval condition (22.5% vs. 38.3%), $t(46) = 2.43$, $p = .019$, $d = .70$. Analysis of variance confirmed the picture and showed a significant interaction between retention interval (short, long) and retrieval condition (prior retrieval, cuing, control), $F(2,138) = 9.71$, $p < .001$, partial $\eta^2 = .12$.

3. Experiment 2

We carried out a second experiment to replicate the results of Experiment 1 and examine whether the results generalize from lists with unrelated words to more integrated prose material. Prose material reflects the complex information that we are confronted with many times a day much better than lists with unrelated words do. Moreover, retrieval-induced forgetting and part-set cuing impairment can numerically be reduced, and may statistically be even absent, with such coherent study material (e.g., Anderson & McCulloch, 1999; Bäuml & Kuhbandner, 2003; Goodmon & Anderson, 2011). Experiment 2, therefore, investigated whether retrieval dynamics are generally reduced with more integrated study material, showing not only reductions in the detrimental effects but also in the beneficial effects of retrieval and cuing. Alternatively, more integrated material may be less subject to inhibition or blocking processes but be more conducive to spreading activation processes, so that the detrimental effects of retrieval and cuing may be reduced but the beneficial effects be still present with this type of material.

3.1. Method

3.1.1. Participants

Another 144 undergraduates took part in the study ($M = 22.7$ years, range = 18–29 years). Again, they received monetary reward for participation.

3.1.2. Materials

Two text passages, *The Shaolin Temple* and *The Big Bang Theory*, which were already used in prior work (Chan, McDermott, & Roediger, 2006), were translated into German and served as study material. Each text was approximately 1800 words long and contained 6 target and 12 nontarget questions (gapped sentences like "The word Shaolin means young _____."[Answer: forest]; "The Hubble telescope found the heavy element _____ in extremely ancient stars." [Answer: boron]).[1]

3.1.3. Design and procedure

Design and procedure were identical to Experiment 1, with the following exceptions: participants had 16 min to read the study text; no initial-letter cues were provided for the answers in the target questions; participants had 25 s to answer a single target or nontarget question; in

[1] English translations of the material (originally in German) are available on request via e-mail to the authors.

the cuing condition, participants were reexposed to the single nontarget sentences which remained present for 25 s each (see Chan et al., 2006).

3.2. Results and discussion

Correct answers to the target questions were less frequent after the long retention interval than after the short retention interval when target questions were answered first (62.5% vs. 26.4%), $t(46) = 6.67$, $p < .001$, $d = 1.92$, thus demonstrating time-dependent forgetting. Like in Experiment 1, retention interval affected retrieval dynamics. After the short retention interval, correct answers to the target questions were numerically, though not statistically, less frequent, both when the nontarget questions were answered first (62.5% vs. 56.3%), $t(46) < 1$, and when the nontargets sentences were presented intact as cues (62.5% vs. 56.3%), $t(46) = 1.12$, $p = .269$. In contrast, after the long retention interval, correct answers to the target questions were more frequent, both when the nontarget questions were answered first (26.4% vs. 41.0%), $t(46) = 2.50$, $p = .016$, $d = .72$, and when the nontarget sentences were presented intact as cues (26.4% vs. 37.5%), $t(46) = 2.17$, $p = .036$, $d = .63$. Analysis of variance confirmed the results and showed a significant interaction between retention interval (short, long) and retrieval condition (prior retrieval, cuing, control), $F(2,138) = 3.57$, $p = .031$, partial $\eta^2 = .05$.

4. Experiment 3

The finding of beneficial effects of memory retrieval after prolonged retention interval in itself leaves it open whether retrieval of items from the same study context was necessary to induce such effects, or whether any retrieval might have produced the effects. In Experiment 3, we therefore compared the effect of prior retrieval of *studied* nontarget items with the effect of prior generation of *unstudied* nontarget items on recall of target items. If engaging in some kind of nontarget retrieval, whether related or not to the target items, primed the retrieval process and thus enhanced target recall, both retrieval of studied nontargets and generation of unstudied nontargets should create beneficial effects of memory retrieval.

4.1. Method

4.1.1. Participants

48 undergraduates took part in the study ($M = 21.1$ years, range = 18–38 years). They received monetary reward for participation.

4.1.2. Materials

The same two study lists were employed as in Experiment 1, consisting of the same 5 target and 10 nontarget items. Each participant studied one of the lists. Nontargets from the other list were used for generation of nontargets in the prior generation condition.

4.1.3. Design and procedure

Retrieval condition was varied between subjects. Participants were either asked to recall the nontargets first and the targets second (prior retrieval condition), recall the targets after prior generation of nontarget items (prior generation condition), or recall the targets only (control condition). Recall was always after a 48-h retention interval. The procedure was identical to Experiment 1 with the only exception that, in the generation condition, participants were presented the word stems of the other list's (unstudied) nontarget items as cues and were asked to generate the first item that came to their mind.

4.2. Results and discussion

Target recall was higher in the prior retrieval than the control condition, (41.3% vs. 21.3%), $t(30) = 2.34$, $p = .026$, $d = .83$, demonstrating the expected beneficial effect of retrieval after prolonged retention interval. In contrast, target recall in the prior generation condition (22.5%) did not differ from control, $t(30) < 1.0$, and was lower than in the prior retrieval condition, $t(30) = 2.22$, $p = .034$, $d = .79$. Because generation of (unstudied) nontargets was successful in most cases (94.4%), the results indicate that the beneficial effect observed in the prior retrieval condition does not reflect a simple priming effect, and prior episodic retrieval is necessary to induce the effect.

5. General discussion

The conceptualization of retrieval as a self-limiting process captures the effects of retrieval and cuing when the retention interval between encoding and recall is short and people's spatial, social, and internal context remains largely unchanged between the two points in time.[2] While such conditions are typical for previous research on retrieval dynamics, they are less typical for people's remembering in daily life. In daily life, the time interval between encoding and recall is often prolonged and people's spatial, social, and internal context changes during the interval. The present study has simulated such conditions and has found retrieval and cuing to improve, rather than impair, retrieval of other memories.

The results for the prolonged retention interval condition mimic recent findings on the role of contextual change for retrieval and cuing processes after short retention interval. These studies found typical retrieval-induced forgetting and part-set cuing impairment when there was no contextual change between encoding and test, but demonstrated beneficial effects of retrieval and cuing when a contextual change between encoding and test was induced (Bäuml & Samenieh, 2012a, 2012b). By showing that the same pattern of results does also arise after prolonged retention interval, the present results underline the critical role of contextual change for longer retention interval (e.g., Baddeley, Eysenck, & Anderson, 2009).

[2] This conceptualization includes the possibility of boundary conditions as they may, for instance, occur with more integrated study material (Experiment 2; see Anderson, 2003).

Bäuml and Samenieh (2012a, 2012b) presented a two-factor account to explain why retrieval can be self-limiting in the absence of a contextual change, but be self-propagating in its presence. The proposal is that, after a change in external or internal context, the original encoding context is deactivated, and prior retrieval of some of the studied items then reactivates the context; such context reactivation can involve associations of items to the context itself (e.g., Howard & Kahana, 2002), or may (additionally) involve the use of direct inter-item associations, with the initially retrieved items serving as a type of episodic contextual cue for still-to-be-recalled items (e.g., Raaijmakers & Shiffrin, 1981). In contrast, in the absence of a context change, the original encoding context remains active and the prior retrieval of some items can inhibit or block access to the other items. According to inhibition, the not-yet-recalled items interfere during prior retrieval and are inhibited to reduce the interference (Anderson, 2003; Anderson & Spellman, 1995); according to blocking, retrieval just strengthens the retrieved items, making them stronger competitors for the other items and thus reducing the other items' recall chances (Raaijmakers & Jakab, 2012; Roediger & Neely, 1982).[3] The present results are consistent with this two-factor account, suggesting that retrieval dynamics are primarily mediated by inhibition or blocking after short retention interval, and by context reactivation after prolonged retention interval.[4,5]

Results from prior work on retrieval-induced forgetting suggest that the detrimental effect of retrieval is recall specific. These studies, for instance, showed that, typically, retrieval but not restudy of some studied items induces forgetting of the other studied items (e.g., Anderson, Bjork, & Bjork, 2000; Bäuml, 2002; Ciranni & Shimamura, 1999). In contrast, the beneficial effect of retrieval may not be recall specific, as is indicated by the view that the effect is mediated by context-reactivation processes (Bäuml & Samenieh, 2012a, 2012b). Indeed, context retrieval theory assumes that, when a previously studied item is repeated, it retrieves the context in which it was originally presented regardless of whether repetition is by virtue of reexposure or its successful recall (Greene, 1989; Howard & Kahana, 2002; Thios & D'Agostino, 1976). It is a high priority for future research on memory retrieval to examine this prediction of the two-factor account, that the detrimental but not the beneficial effect of memory retrieval is recall specific (see Bäuml & Dobler, in press).

[3] There is a lot of debate in the current literature about whether retrieval-induced forgetting is mediated by inhibition or blocking. Because the present experiments were not designed to distinguish between these views, here both accounts are mentioned as possible mechanisms to explain the forgetting.

[4] The present results are consistent with the most simple form of the two-factor account, which assumes that one type of processes is active when context access is maintained, and the other type of processes is active when context access is impaired. In general, a more realistic view will be that both types of processes are active in both conditions, and that the one type of processes dominates the effects in the one condition, and the other type of processes in the other (see Bäuml & Samenieh, 2012a, 2012b).

[5] The two-factor account assumes that prior retrieval from the same study context is necessary to induce the beneficial effect. If so, the effect should no longer be present, if episodic retrieval was from a different study context, a prediction that may be examined in future work.

The present results also offer insights into the nature of cuing effects. It has previously been argued that part-set cuing can lead participants to covertly retrieve the cue items, and that such covert retrieval might be similar in character to overt retrieval and thus induce similar effects on other memories than overt retrieval does (Anderson et al., 1994; Bäuml & Aslan, 2004; Roediger, 1973). Alternatively, the two effects have been attributed to different mechanisms and retrieval-induced forgetting has been explained by inhibition or blocking, whereas part-set cuing impairment has been explained by strategy disruption processes (e.g., Basden & Basden, 1995). The present results are in line with the view of similar underlying mechanisms by finding retrieval and cuing to show not only equivalent detrimental effects (after the short retention interval) but also equivalent beneficial effects (after the long retention interval) on other memories. In particular, the results indicate that not only retrieval but also cuing can reactivate the original study context.

6. Conclusions

Our results show that retrieval dynamics depend critically on situation. Retrieval can be detrimental for other memories after short retention interval and similar context between encoding and test, but can be beneficial after prolonged retention interval with different spatial and social context between encoding and test. Because conditions after the prolonged retention interval mimicked people's remembering in many situations of daily life, our finding indicates that quite often in daily life, retrieval may be a self-propagating, rather than a self-limiting process.

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