The critical role of retrieval processes in release from proactive interference

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ABSTRACT

Proactive interference (PI) refers to the finding that memory for recently studied (target) information can be vastly impaired by the previous study of other (nontarget) information. PI can be reduced in a number of ways, for instance, by directed forgetting of the prior non-target information, the testing of the prior nontarget information, or an internal context change before study of the target information. Here we report the results of four experiments, in which we demonstrate that all three forms of release from PI are accompanied by a decrease in participants' response latencies. Because response latency is a sensitive index of the size of participants' mental search set, the results suggest that release from PI can reflect more focused memory search, with the previously studied nontarget items being largely eliminated from the search process. Our results thus provide direct evidence for a critical role of retrieval processes in PI release.

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Introduction

Proactive interference (PI) refers to the finding that memory for recently studied information can be vastly impaired by the previous study of further information (e.g., Underwood, 1957). In a typical PI experiment, participants study a (target) list of items and are later tested on it. In the PI condition, participants study further (nontarget) lists that precede encoding of the target information, whereas in the no-PI condition participants engage in an unrelated distractor task. Typically, recall of the target list is worse in the PI condition than the no-PI condition, which reflects the PI finding. PI has been extensively studied in the past century, has proven to be a very robust finding, and has been suggested to be one of the major causes of forgetting in everyday life (e.g., Underwood, 1957; for reviews, see Anderson & Neely, 1996; Crowder, 1976).

Over the years, a number of theories have been put forward to account for PI, most of them suggesting a critical role of retrieval processes in this form of forgetting. For instance, temporal discrimination theory suggests that buildup of PI is caused by a failure to distinguish items from the most recent target list from items that appeared on the earlier nontarget lists. Specifically, the theory assumes that at test participants are unable to restrict their memory search to the target list and instead search the entire set of items that have previously been exposed (Baddeley, 1990; Crowder, 1976; Wixted & Rohrer, 1993). Another retrieval account attributes PI to a generation failure. Here, reduced recall levels of the target items are thought to be due to the impaired ability to access the material's correct memory representation (Dillon & Thomas, 1975). In contrast to these retrieval explanations of PI, some theories also suggested a role of encoding factors in PI, assuming that the prior study of other lists impairs subsequent encoding of the target list. For instance, attentional resources may deteriorate across item lists and cause the target material to be less well processed in the presence than the absence of the preceding lists (e.g., Crowder, 1976).

Release from PI

As aggravating PI may be in many situations, experimental results from the past decades have convincingly shown that there are numerous ways in which PI can be reduced. Among these techniques are list-method directed

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forgetting, context change, and interpolated testing. In directed forgetting studies, it has been demonstrated that a cue to forget a previously studied nontarget list can lead to a release from PI and thus to better memory for a subsequently studied target list, relative to a control condition in which participants are asked to remember both lists (e.g., Bjork, 1970, 1989). In context-change studies, it has been shown that an internal context change between the prior study of a nontarget list and the subsequent study of a target list can reduce PI, relative to a control condition without such context change (e.g., Pastötter & Bäuml, 2007; Sahakyan & Kelley, 2002). Studies on interpolated testing have demonstrated that testing previously studied nontarget lists before subsequent encoding of the target list can result in better memory for the target information, relative to a control condition without such testing of the prior information (e.g., Szpunar, McDermott, & Roediger, 2008; Tulving & Watkins, 1974; for further demonstrations of PI release, see Jacoby, Wahlheim, Rhodes, Daniels, & Rogers, 2010; Wixted & Rohrer, 1993).

For each of the three techniques – directed forgetting, context change, and interpolated testing – often retrieval explanations have been put forward to account for the release from PI. Such retrieval explanations center on the view that directed forgetting of nontarget material, a change in internal context between prior nontarget and subsequent target encoding, and the interpolated testing of the prior nontarget material can reduce interference of the prior nontarget information at test and thus improve recall of the target items. Such interference reduction has been suggested to be mediated by inhibitory processes that reduce accessibility of the nontarget items (directed forgetting; e.g., Geiselman, Bjork, & Fishman, 1983), by the induced mismatch between encoding and test context for the nontarget items (directed forgetting; context-dependent forgetting; e.g., Sahakyan & Kelley, 2002), or by enhanced list segregation as caused by the preceding retrieval practice on the nontarget items (interpolated testing; Szpunar et al., 2008).

In contrast, more recent accounts in the three paradigms have favored encoding explanations of release from PI. These explanations center on the view that each of the techniques improves subsequent encoding of the target list. Such improvement has been suggested to be mediated by a change in people's encoding strategy, with more elaborate encoding of the target list if the nontarget material was intentionally forgotten or subject to a context change (directed forgetting; context change; e.g., Sahakyan & Delaney, 2003, 2005), or by a reset of the encoding process supposed to make the encoding of the later target list as effective as the encoding of earlier nontarget lists; such reset processes have been suggested to be triggered in response to a forget cue (Pastötter & Bäuml, 2010), a context change (Pastötter, Bäuml, & Hanslmayr, 2008), and interpolated testing (Pastötter, Schicker, Niedernhuber, & Bäuml, 2011).

The possible role of search set size in PI and release from PI

The finding that encoding processes can influence PI release challenges the view of a critical role of retrieval processes in PI release. Indeed, although previous retrieval accounts of PI release have repeatedly argued that PI release may result from reduced interference of the prior nontarget information when the target items are recalled (e.g., Bjork, 1989; Sahakyan & Kelley, 2002; Szpunar et al., 2008), this proposal has never been tested directly. This study comes up with such a test by examining directly whether, with release from PI, participants are able to restrict their memory search to the target list, rather than searching the entire set of target and nontarget items that have previously been exposed. The suggestion that participants' search set size may play a role in release from PI is also motivated by a previous PI study.

In this previous PI study, Wixted and Rohrer (1993) exposed participants to a short target list, with or without prior study of further nontarget lists. As expected, after study of the nontarget lists, PI built up for the most recent list, as reflected in the reduced percentage of correctly recalled items. Analyzing participants' response latencies, the authors additionally found an increase in response latency for the target list when preceding lists were studied. Because response latency is a sensitive index of the size of participants' mental search set (see below), the slowing of the retrieval process points to an increase in participants' search set size when PI arises. This increase was interpreted as evidence that PI builds up as a result of a growing inability to distinguish items that appeared on the target list from items that appeared on the preceding nontarget lists, which supports temporal discrimination theory.

The present study extends Wixted and Rohrer's (1993) prior PI work to release from PI by examining (i) whether retrieval processes play a critical role not only in buildup of PI but also in release from PI, and (ii) whether changes in participants' search set size mediate both build up of PI and release from PI. The first goal of the present study was to replicate Wixted and Rohrer's (1993) finding by showing that response latency of target information increases when PI is built up, suggesting that the size of participants' search set increases with PI. The second goal was to examine whether release from PI is accompanied by a decrease in response latency and thus by a reduction in participants' search set size. Such a pattern of results would indicate that retrieval processes play a critical role in both buildup of PI and release from PI, and that both effects can be mediated through modulations in participants' search set size. We used directed forgetting, interpolated testing, and context change techniques to induce a release from PI. To examine participants' latencies we used response latency analysis.

Response latency analysis

Typically, studies of episodic forgetting focus on response total – i.e., the percentage of recalled items within a certain period of time – as the dependent measure, whereas response latency – i.e., the speed of recall – is ignored. Such proceeding may be justified if the two measures capture largely the same underlying processes. However, there is evidence that response total and response latency do not always covary but rather are independent. For instance, Rohrer and Wixted (1994) demonstrated that a reduction in list length increases response totals and

decreases response latencies, whereas an increase in item exposure time improves response totals but leaves response latencies unaffected. Bäuml, Zellner, and Vilimek (2005) found that retrieval practice of a subset of studied items reduces response totals for related unpracticed items but does not influence the items' response latencies. Rohrer, Salmon, Wixted, and Paulsen (1999) reported differences in response latencies but not in response totals across different clinical populations. Obviously, response latencies provide unique information about the process of retrieval and thus can add something to our understanding of memory processes.

Analysis of response latencies over a wide range of experiments has revealed that participants typically remember many items early in the recall period and relatively few items later in the recall period. Consistently, response latencies have been found to be well described by the 2-parameter exponential,

$$r(t) = (N/\tau)e^{-t/\tau},$$

where $r(t)$ represents the number of items recalled at a particular time interval t, N represents asymptotic recall (the estimated number of items that could be produced given unlimited time), and τ represents the mean response latency of those N items (Bousfield & Sedgewick, 1944). McGill's (1963) random-search model was the first to use the exponential as a description of the time course of recall. According to this model, items are sampled randomly from a mental search set, one item at a time, at a constant rate. Each sampled item is then classified as either "has already been sampled", in which case it is ignored, or as "has not yet been sampled", in which case it is recalled. Subsequently, every sampled item is replaced into the search set. Although the random search model is an oversimplification of retrieval (Herrmann & Pearle, 1981; Morrison, 1979; Vorberg & Ulrich, 1987), it has proven an extremely useful and robust account of response latencies (see Wixted & Rohrer, 1994, for a review). In particular, the very useful heuristic prediction of a linear relationship between mean response latency (τ) and the size of participants' search set in the task arises, which indicates that mean response latency (τ) can be used as an index of participants' search set size (e.g., Rohrer, 1996).

The present experiments

This study examines buildup of PI and release from PI in three experimental situations: list-method directed forgetting (Bjork, 1970; Experiments 1A and 1B), interpolated testing (Szpunar et al., 2008; Experiment 2), and context change (Sahakyan & Kelley, 2002; Experiment 3). In each experiment, response totals as well as response latencies of a target list are analyzed. Each experiment includes three experimental conditions, in each of which a target list is studied and tested: in the *no-PI condition*, only the target list is studied and there is an unrelated distractor task before; in the *PI condition*, forgetting of the target list is induced through the prior study of further (nontarget) lists; in the *release-from-PI condition*, nontarget lists are studied before encoding of the target items but PI is

reduced, either by cuing participants to forget the previously studied nontarget lists before encoding the target list (Experiments 1A, 1B), by testing the previously studied nontarget lists before encoding the target list (Experiment 2), or by means of a context change after study of the nontarget lists (Experiment 3).

We expected to find buildup of PI in each of the single experiments, reflected in both decreased response totals and increased response latencies for the target items in the PI-condition relative to the no-PI condition (e.g., Underwood, 1957; Wixted & Rohrer, 1993). Replicating the prior literature on directed forgetting, interpolated testing, and context change, we also expected to find enhanced target recall in each of the release-from-PI conditions, relative to the respective PI conditions. Most importantly, following the hypothesis that retrieval processes play a critical role in release from PI, and release from PI can be due to more focused memory search, we expected to find shorter response latencies in each of the three release-from-PI conditions, relative to the PI conditions; if the release techniques canceled the PI-induced increase in search set size completely, latencies in the release-from-PI conditions might even be equal to latencies in the no-PI conditions.

Prior work on response latency analysis often distinguished between first-response and subsequent-response latency (e.g., Bäuml et al., 2005; Rohrer, Wixted, Salmon, & Butters, 1995). First-response latency measures the average duration until the onset of the first recalled item and is thought to reflect the initiation of the search set; subsequent-response latency measures the duration between the first response and each subsequent response and is assumed to capture retrieval from the search set, therefore being a purer measure of the recall process itself (for a discussion, see Rohrer et al., 1995). The results by Wixted and Rohrer (1993) reported evidence that the buildup of PI does not affect the initiation process but affects the recall process itself. On the basis of this result, we expected to find both buildup of PI and release from PI to be reflected mostly in participants' subsequent-response latencies and less, if at all, in their first-response latencies.

Experiment 1A

Experiment 1A employed a list-method directed forgetting task to examine buildup of PI and release from PI. The experiment included three experimental conditions. In the forget condition and the remember condition, participants studied a nontarget list and subsequently a target list. Between study of the two lists, they received a cue either to forget (forget condition) or to continue remembering (remember condition) the previously presented nontarget list (e.g., Bjork, 1970, 1989). In the no-PI condition, participants studied the target list only, preceded by an unrelated distractor task. The remember condition served as the PI condition and the forget condition as the release-from-PI condition in this experiment. After study of the target list, in all three conditions memory for the items of this list was tested; both response totals and response latencies were measured.

On the basis of prior work on list-method directed forgetting (for reviews, see MacLeod, 1998; Bäuml, Pastötter, & Hanslmayr, 2010), we expected to find both buildup of PI and release from PI in this experiment. We expected to find reduced target recall in the PI-condition (remember condition) relative to the no-PI condition, and enhanced target recall in the release-from-PI condition (forget condition) relative to the PI-condition (remember condition). Response totals in the release-from-PI condition (forget condition) and the no-PI condition might even be similar (e.g., Bjork & Bjork, 1996), which would indicate a perfect release from PI in terms of response totals.

Regarding response latencies, we expected to find increased latencies in the PI-condition (remember condition) relative to the no-PI condition, thus replicating results from prior work (Wixted & Rohrer, 1993). More important, on the basis of the hypothesis that a reduction in search set size contributes to release from PI, we expected reduced latencies in the release-from-PI condition (forget condition) relative to the PI-condition (remember condition). Both buildup of PI and release from PI should be reflected mainly in subsequent-response latencies and less, if at all, in first-response latencies (e.g., Rohrer et al., 1995; Wixted & Rohrer, 1993). The expected results would indicate that, in directed forgetting, a reduction in the size of participants' mental search set plays a critical role in release from PI, so that, if a forget cue is provided, participants are able to (largely) restrict their memory search to the target items.

Methods

Participants. Twenty-four healthy students at Regensburg University (Regensburg, Germany) took part in the experiment on a voluntary basis. They received 7 Euros for their participation. The sample consisted of 19 females and 5 males. Their mean age was 22.51 years with a range of 19–26 years. All participants spoke German as their native language. They were tested individually.

Materials. One hundred and twenty unrelated nouns of medium frequency were drawn from the CELEX database using the Wordgen v1.0 software toolbox (Duyck, Desmet, Verbeke, & Brysbaert, 2004). Twelve items were assigned to each of 10 lists. For each participant, the ten lists were distributed across the three experimental conditions; four lists were assigned to the remember condition, four lists to the forget condition, and two lists to the no-PI condition. Across lists, words were matched on frequency and word length. Each list was used equally often in the remember condition, the forget condition, and the no-PI condition.

Design. The experiment was composed of three conditions: the forget condition, which served as the release-from-PI condition; the remember condition, which served as the PI condition; and the no-PI condition. Participants always studied a target list (List 2). Conditions differed as to what happened before target-list encoding. In the forget and remember conditions, the list of nontarget items (List 1) was presented; in the forget condition, List 1 was followed by the cue to forget the list; in the remember condition, List 1 was followed by the cue to remember the list

for an upcoming test. In the no-PI condition, there was no prior study of another list (e.g., Bjork & Bjork, 1996).

Procedure. All participants were told that several item lists would need to be studied and that following each list they would be given a cue to either remember or forget the preceding list. It was highlighted that the remember cue specified that the preceding list would be tested later, whereas the forget cue specified that it would not. Each participant took part in two successive experimental blocks, each block consisting of a forget condition, a remember condition, and a control condition in random order. Each of the conditions consisted of a study phase, a distractor phase, and a test phase. In the study phase, participants were always presented the target list, followed by an instruction to remember the list. In the no-PI condition, participants solved arithmetic problems for 1 min before studying the target list, whereas in the remember condition and the forget condition, participants were presented with List 1. Item order within lists was random for each participant. Each item was presented individually on a computer screen at a rate of 5 s per item. The distractor phase was the same in every condition and served as a recency control. It lasted for 1 min and participants were told to orally group blocks of five digits in an ascending order. Following the distractor phase, participants were given 1 min to remember as many items as possible from the target list in any order the participants wished. List 1 items were recalled in the remember condition only, but the results are not reported. Between the single experimental conditions, there was a break of 30 s before the next condition started.

The participants' answers 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 (see Bäuml et al., 2005).

Measure of latency. For each of the three conditions (forget, remember, no PI), first-response latencies and subsequent-response latencies were analyzed. Exponential functions were fitted to the subsequent-response latency functions of each condition in order to analyze retrieval dynamics (see Introduction). Two parameters describe those functions – N representing asymptotic recall and τ representing the mean latency of those N items – which were derived from fitting the exponential to the data. The best fitting exponentials were determined by least square minimization. Using the asymptotic standard error for each parameter, pairwise comparisons of parameter values were performed by a t-test. For these t-tests, the asymptotic standard error of each parameter value provided a measure of the variability of each parameter, and the degrees of freedom for each of the two curve fits, summed together, provided the number of degrees of freedom (for details, see Rohrer et al., 1995).

Results

Response totals. Participants correctly recalled 67.00% of the target items in the forget condition, 55.73% in the

remember condition, and 70.31% in the no-PI condition. An overall ANOVA of the three conditions (forget, remember, no PI) showed a significant effect of condition, $F(2, 46) = 8.787$, $MSE = 0.100$, $p = 0.002$, $\eta_p^2 = 0.444$. Pairwise comparisons revealed that the difference of 14.58% between the no-PI condition and the remember condition was reliable, $t(23) = 4.263$, $p < 0.001$, $d = 1.342$, illustrating the buildup of PI from the no-PI condition to the remember condition. The difference of 11.27% in recall between the forget condition and the remember condition was also statistically significant, $t(23) = 3.491$, $p = 0.002$, $d = 1.069$, reflecting release from PI in the forget condition compared to the remember condition. There was no significant difference between the no-PI condition and the forget condition, $t(23) = 1.405$, $p = 0.173$, reflecting almost complete release from PI in the forget condition. The mean rate of intrusions from the nontarget list during target recall was 4.51% in the forget condition and 2.26% in the remember condition; the difference was not reliable, $t(23) = 1.701$; $p = 0.102$.

Response latencies. Table 1 shows the first-response latencies of the target list for the three conditions. First-response latencies were 1.36 s in the forget condition, 1.57 s in the remember condition, and 1.32 s in the no-PI condition. An overall ANOVA of the three conditions (forget, remember, no PI) revealed no significant effect of condition, $F(2, 46) = 1.709$, $MSE = 0.206$, $p = 0.192$, suggesting that first-response latencies did not depend on condition.

Subsequent-response latencies were grouped into 5-s bins and plotted as a function of time (see Fig. 1A). Each data point represents the average percentage of items that were produced in that 5-s bin. Fig. 1A also shows the best-fitting two-parameter exponential for each of the three conditions. As can be seen from Table 1, the exponential accounts for a large portion of the variance in each condition. The parameter estimate of asymptotic percentage (N) revealed values of 59.35% for target list recall in the forget condition, 47.67% in the remember condition, and 61.78% in the no-PI condition. Because N is based on subsequent responses only, whereas percentage recalled includes first responses as well, we computed corrected measures, in which only the subsequent responses were included. The corrected values – 58.67% in the forget condition, 47.40% in the remember condition, and 62.00% in the no-PI condition – were very similar to the estimated values of N. This indicates that recall was close to asymptote in Experiment 1A, a feature well reflected in Fig. 1A.

Table 1

Response totals (i.e., percentage of recalled items) and response latencies (in seconds) for the target list in Experiments 1A and 1B (standard errors in parentheses). VAF = variance accounted for by the exponential.

Condition	% Recalled	First-response latency	Subsequent-response latency (τ)	VAF
Experiment 1A				
Forget	67.00 (3.84)	1.36 (0.09)	9.18 (0.33)	0.99
Remember	55.73 (4.92)	1.57 (0.14)	10.73 (0.60)	0.99
No PI	70.31 (3.46)	1.32 (0.07)	9.29 (0.35)	0.99
Experiment 1B				
Forget	67.71 (3.22)	1.31 (0.10)	8.13 (0.36)	0.99
Remember	41.32 (4.53)	1.85 (0.32)	10.86 (0.92)	0.97
No PI	68.40 (3.85)	1.22 (0.08)	8.65 (0.39)	0.99

The main focus in the current study was on mean subsequent-response latency (τ). These values were 9.18 s in the forget condition, 10.73 s in the remember condition, and 9.29 s in the no-PI condition. The difference of 1.44 s between the no-PI condition and the remember condition was reliable, $t(20) = 2.089$, $p = 0.049$, demonstrating that the buildup of PI was not only reflected in response totals but also in the subsequent-response latency measure. The difference of 1.55 s between the forget condition and the remember condition was also statistically significant, $t(20) = 2.263$, $p = 0.035$, which shows the diminished PI in the forget condition. The difference of 0.11 s between the forget condition and the no-PI condition was not reliable, $t(20) < 1$, illustrating that speed of recall did not differ between the release-from-PI and the no-PI condition.

Discussion

The results of Experiment 1A replicate prior work on buildup of PI by showing reduced response totals and increased response latencies for the target list when a nontarget list was studied previously (e.g., Underwood, 1957; Wixted & Rohrer, 1993). The effect on latencies was mainly driven by an effect on subsequent-response latencies but not on first-response latencies, suggesting an effect on retrieval from the search set rather than retrieval initiation. These results are consistent with the temporal discrimination theory of PI (Baddeley, 1990; Crowder, 1976), indicating that, in PI, participants may not be able to restrict their memory search to the target list and instead search other (nontarget) items that have previously been exposed.

Regarding release from PI, the results on response totals show enhanced recall for the target items when, before study of the target list, a cue was presented to forget the previously presented nontarget list (e.g., Bjork, 1989; MacLeod, 1998); the release from PI was even complete, which is consistent with previous studies (e.g., Bjork & Bjork, 1996). The results on response latencies show reduced response latencies for the target items when a forget cue was provided between study of the two lists; remarkably, latencies in the forget condition were even indistinguishable from those in the no-PI condition, indicating that, in response to the forget cue, speed of recall was no longer affected by the prior study of the nontarget list. Similar to the buildup of PI, the effect on latencies was driven mainly by an effect on subsequent-response latencies, suggesting an effect on retrieval from the search set. The results are consistent with the view that providing a forget cue between prior study of a nontarget list and subsequent study of a target list enhances list discrimination and reduces participants' search set size when target items are recalled.

Experiment 1B

The results of Experiment 1A suggest that list-method directed forgetting can induce a complete release from PI, both with regard to response totals and response latencies. The size of the PI effect observed in Experiment 1A was typical for 2-list paradigms, being on the order of 10–15% with regard to response totals (e.g., Bjork & Bjork, 1996;
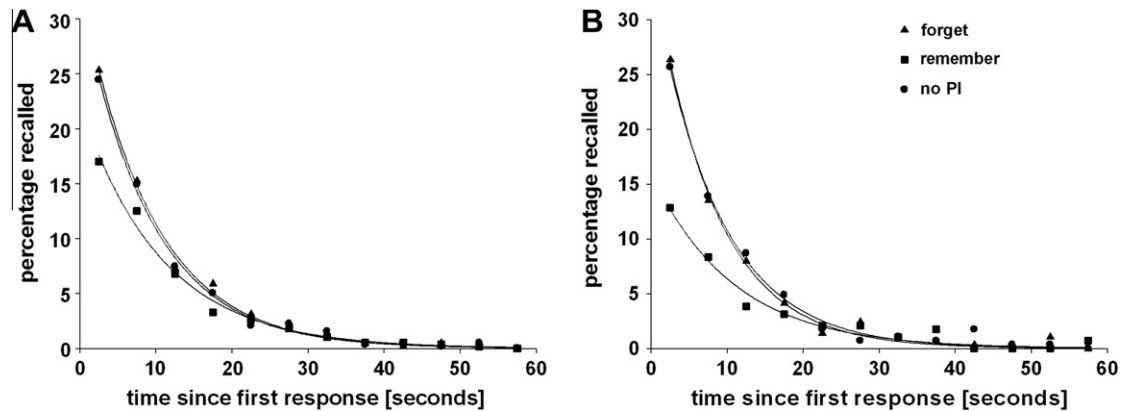
Fig. 1. (A) Results of Experiment 1A: Target recall – percentage of recalled items – for each 5-s bin in the forget (PI-release), the remember (PI), and the control (no-PI) condition together with the best fitting exponentials. Latency is measured from the first response (PI = proactive interference). (B) Results of Experiment 1B: Target recall - percentage of recalled items – for each 5-s bin in the forget (PI-release), the remember (PI), and the control (no-PI) condition together with the best fitting exponentials (PI = proactive interference) Latency is measured from the first response.

Sahakyan & Foster, 2009). To examine whether directed forgetting still causes complete release from PI if the PI effect is enlarged, we studied list-method directed forgetting in a 3-list paradigm, in which two nontarget lists were studied prior to study of the target list. It was examined whether a cue to forget the two nontarget lists still eliminated PI, leading to response totals and response latencies that are similar to a no-PI condition.

Methods

Participants. Twenty-four healthy students at Regensburg University took part in the experiment on a voluntary basis. They received 5 Euros for their participation. The sample consisted of 19 females and 5 males. Their mean age was 24.86 years with a range of 10–34 years. All participants spoke German as their native language. They were tested individually.

Materials. Seven lists of 12 items each were created by drawing 72 items from the pool of the 120 items that were generated for Experiment 1A. Mean item length and item frequency were held constant across lists. For each participant, three lists were randomly assigned to the remember condition, three lists to the forget condition, and one list to the no-PI condition.

Design and procedure. Design and procedure were identical to Experiment 1A with the exception that two precue lists were studied in the forget and remember conditions. Consistently, in the no-PI condition, participants solved arithmetic problems for 2 min before encoding the target list. Similar to Experiment 1A, only items from the target list were tested in the forget condition, whereas in the remember condition participants recalled the target list first, and the two nontarget lists second; again, nontarget results are not reported. The participants' answers were recorded and analyzed identical to Experiment 1A.

Results

Response totals. Participants correctly recalled 67.71% of the target items in the forget condition, 41.32% in the

remember condition, and 68.40% in the no-PI condition. An overall ANOVA of the three conditions (forget, remember, no PI) showed a significant effect of condition, $F(2, 46) = 26.218$, $MSE = 0.022$, $p < 0.001$, $\eta_p^2 = 0.533$. Pairwise comparisons revealed that the difference of 27.08% in percentage recalled between the no-PI condition and the remember condition was statistically significant, $t(23) = 5.652$, $p < 0.001$, $d = 1.440$, reflecting the buildup of PI from the no-PI condition to the remember condition. The difference of 26.39% between the forget condition and the remember condition was also reliable, $t(23) = 6.088$, $p < 0.001$, $d = 1.792$, demonstrating a release from PI in the forget condition. The difference of 0.69% between the forget condition and the no-PI condition was not reliable, $t(23) = 0.194$, $p = 0.848$, pointing to a complete release from PI in the forget condition. The mean rate of intrusions from the two nontarget lists during target recall was 4.92%, in both the forget condition and the remember condition.

Response latencies. Table 1 shows the first-response latencies of the target list for the three conditions. First-response latencies were 1.31 s in the forget condition, 1.85 s in the remember condition, and 1.22 s in the no-PI condition. An overall ANOVA of the three conditions (forget, remember, no PI) showed a marginally significant effect, $F(2, 46) = 3.151$, $MSE = 0.806$, $p = 0.053$, $\eta_p^2 = 0.130$. Pairwise comparisons showed no significant differences between the forget and the remember condition, $t(23) = 1.603$, $p = 0.124$, and between the forget and the no-PI condition, $t(23) < 1$; the difference between the no-PI condition and the remember condition was marginally significant, $t(23) = 2.033$, $p = 0.055$. Thus, similar to Experiment 1A, first-response latencies did not depend much on PI condition.

Subsequent-response latencies were grouped into 5-s bins and plotted as a function of time (see Fig. 1B). Fig. 1B also shows the best-fitting exponentials. The exponential accounts for a large portion of the variance in each of the three conditions (see Table 1). The parameter estimate of asymptotic percentage (N) revealed values of 57.88% for target list recall in the forget condition, 34.70% in the remember condition, and 59.12% in the no-PI condition.

Again, corrected totals – 59.38% in the forget condition, 32.00% in the remember condition, and 60.07% in the no-PI condition – were very similar to the estimated values of N. This indicates that recall was close to asymptote in the current experiment.

Estimated subsequent-response latencies were 8.13 s in the forget condition, 10.86 s in the remember condition, and 8.65 s in the no-PI condition. The difference of 2.21 s between the no-PI condition and the remember condition was reliable, $t(20) = 2.210$, $p = 0.039$, reflecting the buildup of PI in the subsequent-response latency measure. The difference of 2.73 s between the forget condition and the remember condition was statistically significant, $t(20) = 2.760$, $p = 0.012$, pointing to reduced PI in the forget condition. The difference of 0.52 s between the forget condition and the no-PI condition was not reliable, $t(20) < 1$, again demonstrating an almost perfect release from PI in the forget condition.

Discussion

Using a 3-list paradigm, the results of Experiment 1B replicate those of Experiment 1A with the 2-list paradigm. They show buildup of PI from the no-PI condition to the remember condition, reflected in decreased response totals and increased response latencies; and they show release from PI from the remember condition to the forget condition, reflected in increased response totals and decreased response latencies. Again, the latency effects were present in the subsequent-response latencies, but not in first-response latencies, suggesting effects in retrieval from search set but not in retrieval initiation.

Although the PI effect in response totals as well as the PI effect in response latencies were considerably larger in the present experiment than in Experiment 1A, again release from PI was complete, leading to similar response totals and similar latencies in the forget condition than in the no-PI condition. [1] Like the results of Experiment 1A, the results of Experiment 1B thus are consistent with the view that directed forgetting of previously studied nontarget material reduces participants' search set size when target items are recalled. Because release from PI was complete in response latency, the results suggest that, in directed forgetting, the search set during target recall hardly contains any items from the nontarget list(s). The finding is consistent with the view of a critical role of 'set differentiation' in directed forgetting (e.g., Bjork, 1970; MacLeod, 1998), according to which segregation between previously studied nontargets and recently studied targets can serve as a crucial mechanism to create successful release from PI.

Experiments 1A and 1B are not the first experiments to study response latencies in list-method directed forgetting. In a recent study, Spillers and Unsworth (2011) addressed

the issue as well. However, whereas in the present study the focus was on release from PI and postcue item recall and subjects were asked to recall the postcue items first, in this prior work the focus was on List-1 forgetting and precue item recall and subjects were asked to recall the precue items first. Recent work has shown that release from PI arises mainly if postcue items are recalled first and may be reduced, or even be eliminated, if the precue items are recalled first (Pastötter, Kliegl, & Bäuml, 2012). Supporting this view, Spillers and Unsworth did not find any evidence for PI release, both in response totals and response latencies, whereas Experiments 1A and 1B of the present study demonstrate release from PI, both in response totals and response latencies. The present experiments thus go beyond this prior work by demonstrating for the first time that release from PI in response to a forget cue is accompanied by a reduction in mental search set size.

Experiment 2

The goal of Experiments 2 and 3 was to investigate whether the pattern observed in Experiments 1A and 1B is specific to directed forgetting, or generalizes to other forms of release from PI, like interpolated testing and context change. Like Experiment 1B, Experiment 2 employed a 3-list paradigm to examine buildup of PI and release from PI. In contrast to Experiment 1B, the present experiment examined how testing of previously studied nontarget lists induces PI release. Like Experiments 1A and 1B, the experiment included three experimental conditions. In the no-PI condition, participants studied the target list, preceded by an unrelated distractor task. In the other two conditions, participants studied two nontarget lists before they were presented the target list; in the restudy condition, each of the two nontarget lists was reexposed after study to provide opportunity for additional learning, whereas in the testing condition, participants were asked to recall each of the two nontarget lists after list study. Szpunar et al. (2008) showed that interpolated testing but not restudy of the nontarget lists can insulate against PI, with restudy of the single lists being similar in effect to participants' engagement in an unrelated distractor task (see also Pastötter et al., 2011; Weinstein, McDermott, & Szpunar, 2011). The restudy condition served as the PI condition and the testing condition as the release-from-PI condition in the present experiment. After study of the target list, in all three conditions memory for the items of this list was tested; both response totals and response latencies were measured.

On the basis of the results of Experiment 1B and prior work on interpolated testing (e.g., Pastötter et al., 2011; Szpunar et al., 2008), we expected to find both buildup of PI and release from PI in this experiment. We expected to find reduced target recall in the PI-condition (restudy condition) relative to the no-PI condition, and enhanced target recall in the release-from-PI condition (testing condition) relative to the PI-condition (restudy condition). If interpolated testing was similar in amount of PI release to list-method directed forgetting, response totals in the

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[1] Experiments 1A and 1B employed a within-subjects design, so that recall in the no-PI conditions may have been affected by PI from prior lists. Arguably, this feature may have created nonspecific interference effects, which may have influenced the observed degree of PI release. However, using a between-subjects design, prior work also reported full release from PI (e.g., Bjork, 1989; Bjork & Bjork, 1996), indicating that the effect of the within-subjects design on the present results should have been minor at best.

release-from-PI condition (testing condition) and the no-PI condition might even be similar, which would point to a perfect release from PI with interpolated testing.

Regarding response latencies, we expected increased latencies in the PI-condition (restudy condition) relative to the no-PI condition. More important, on the basis of the hypothesis that a reduction in search set size contributes to PI release, we again expected reduced latencies in the release-from-PI condition (testing condition) relative to the PI-condition (restudy condition). Like in Experiments 1A and 1B, both buildup of PI and release from PI were expected to be mainly reflected in subsequent-response latencies and less, if at all, in first-response latencies. The expected results would indicate that, like directed forgetting, interpolated testing can reduce PI by a reduction in the size of participants' search set.

Methods

Participants. Thirty healthy students at Regensburg University took part in the experiment on a voluntary basis. They received 7 Euros for their participation. The sample consisted of 21 females and 9 males. Their mean age was 23.43 years with a range of 20–26 years. All participants spoke German as their native language. They were tested individually.

Materials. Like in Experiment 1B, seven lists of 12 items each were created by drawing 72 items from the pool of the 120 items that were generated for Experiment 1A, with mean item length and item frequency being held constant across lists. For each participant, three lists were randomly assigned to the interpolated testing condition, three lists to the restudy condition, and one list to the no-PI condition.

Design and procedure. Each participant took part in three conditions: the testing condition, the restudy condition, and the no-PI condition. Each condition consisted of a study phase, a distractor phase, and a test phase. In the study phase, participants always studied the target list (List 3). Conditions differed as to what happened before target-list encoding. In the testing and restudy conditions, participants were presented with two preceding lists. The presentation of each preceding list was followed by a 1 min backward-counting task. The testing and the restudy conditions then differed in the interlist activity that followed each list's backward counting task: in the testing condition, participants were given 1 min to orally recall in any order they wished as many words as possible from the list they had just studied; the responses were recorded. In the restudy condition, the items from the just studied list were reexposed for further study. In the no-PI condition, no preceding lists were studied and participants solved arithmetic problems for 6 min before being presented with the target list. Item order was random within lists for each participant, and each single item was presented individually on the computer screen for 5 s. The distractor phase was the same in each condition and served as a recency control; participants were asked to orally group blocks of five digits in an ascending order for 1 min.

Following Szpunar et al. (2008), the test phase was composed of two tests in the testing and restudy conditions: an immediate test on the target list and a final

cumulative test on all three lists. In the immediate test, which took place directly after the distractor phase that followed encoding of the target list, participants were asked to orally recall the items from the previous list (List 3) for 1 min in any order they wished. In the final cumulative test, participants were given 3 min to recall in any order they wished as many words as possible from all three lists of words they had studied. They wrote down the words on a sheet of paper. Between the immediate test and the final test, participants dealt with short reasoning tasks for 2 min. In the no-PI condition, the test phase consisted of the immediate test only. Results of the final test are of no relevance for the present study and thus will not be reported. The participants' responses on the immediate test and the tests following List 1 and List 2 in the testing condition were recorded and analyzed in exactly the same way as participants' responses on the test of the target list(s) in Experiments 1A and 1B.

Results

Response totals. Participants correctly recalled 72.78% of the target items in the testing condition, 58.89% in the restudy condition, and 71.11% in the no-PI condition. An overall ANOVA of the three conditions (testing, restudy, no PI) revealed a significant effect, $F(2, 58) = 5.411$, $MSE = 0.032$, $p = 0.007$, $\eta_p^2 = 0.157$. Pairwise comparisons showed that the difference of 12.12% between the restudy condition and the no-PI condition was reliable, $t(29) = 2.138$, $p = 0.041$, $d = 0.512$, demonstrating the buildup of PI as caused by the study (and restudy) of preceding material. The difference of 13.89% between the restudy condition and the testing condition was also significant, $t(29) = 2.924$, $p = 0.007$, $d = 0.749$, showing the beneficial effect for the target list when the preceding material was tested compared to when it was restudied. The difference of 1.78% between the testing condition and the no-PI condition was not reliable, $t(29) < 1$, reflecting the perfect release from PI as caused by the interpolated testing. The mean rate of intrusions from the two nontarget lists during target recall was 0.55% in the testing condition and 1.39% in the restudy condition; the difference was not significant, $t(23) < 1$.

Response latencies. First-response latencies of the target list were 1.42 s in the testing condition, 2.29 s in the restudy condition, and 1.46 s in the no-PI condition (see Table 2). An overall ANOVA of the three conditions (testing, restudy, no PI) revealed a marginally significant difference, $F(2, 58) = 2.747$, $MSE = 0.102$, $p = 0.075$. Pairwise comparisons across conditions showed no significant differences between conditions, all $ps > .10$, suggesting that first-response latencies did not vary much with condition.

Like in Experiments 1A and 1B, subsequent-response latencies were grouped into 5-s bins and plotted as a function of time (see Fig. 2). The data points were well described by the two-parameter exponential, which accounts for a large portion of the variance in each condition (see Table 2). The parameter estimate of asymptotic percentage (N) revealed values of 62.66% for target list recall in the testing condition, 51.17% in the restudy condition, and 59.78% in the no-PI condition. Like in

Table 2
Response totals (i.e., percentage of recalled items) and response latencies (in seconds) of the target list, List 1, and List 2 for Experiment 2 (standard errors in parentheses). VAF = variance accounted for by the exponential.

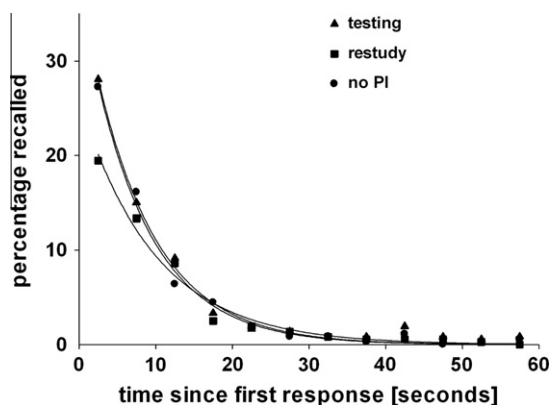|	Condition	% Recalled	First-response latency	Subsequent-response latency (τ)	VAF
Target list	Testing	72.78 (3.48)	1.42 (0.08)	8.10 (0.44)	0.99
	Restudy	58.89 (5.39)	2.29 (0.54)	9.87 (0.73)	0.98
	No PI	71.11 (3.74)	1.46 (0.09)	7.88 (0.40)	0.99
List 1	Testing	74.17 (4.08)	1.19 (0.06)	7.73 (0.51)	0.99
List 2	Testing	69.44 (3.84)	1.41 (0.09)	8.61 (0.94)	0.96

Fig. 2. Results of Experiment 2: Target recall – percentage of recalled items – for each 5-s bin in the interpolated testing (PI-release), the restudy (PI), and the control (no-PI) condition together with the best fitting exponentials (PI = proactive interference). Latency is measured from the first response.

Experiments 1A and 1B, corrected totals – 64.45% in the testing condition, 50.56% in the restudy condition, and 62.78% in the no-PI condition – were very similar to the estimated values of N. This indicates that recall was close to asymptote in the current experiment.

Estimated mean subsequent-response latencies of the target list were 8.10 s in the testing condition, 9.87 s in the restudy condition, and 7.88 s in the no-PI condition. The difference of 1.99 s between the no-PI condition and the restudy condition was reliable, $t(20) = 2.391$, $p = 0.027$, demonstrating the buildup of PI from the no-PI to the restudy condition. The difference of 1.77 s between the testing and the restudy condition was also reliable, $t(20) = 2.091$, $p = 0.049$, pointing to diminished PI in the testing condition. Recall in the testing and no-PI conditions did not differ statistically, $t(20) < 1$, illustrating that speed of recall did not differ between the release-from-PI and the no-PI condition.

Nontarget recall. Within the interpolated testing condition, an overall ANOVA showed no significant difference in recall levels between List 1, List 2, and the target list, $F(2, 58) < 1$. Regarding response latencies, an overall ANOVA revealed a marginally significant increase in first-response latencies from List 1 to the target list, $F(2, 58) = 2.734$, $MSE = 0.155$, $p = 0.075$, whereas subsequent-response latencies did not differ between any of the single lists, all $ts(29) < 1$ (see Table 2).

Discussion

The results of Experiment 2 replicate those of Experiments 1A and 1B on buildup of PI by showing reduced response totals and increased response latencies for the target list when nontarget lists were studied (and restudied) before target list encoding. Again, the effect on latencies was mainly driven by an effect on subsequent-response latencies but not on first-response latencies, suggesting an effect on retrieval from the search set rather than retrieval initiation, which is consistent with temporal discrimination theory (Baddeley, 1990; Crowder, 1976).

Regarding release from PI, the results on response totals replicate prior work by Szpunar et al. (2008) and Pastötter et al. (2011) by showing enhanced target recall when, before study of the target list, the nontarget lists were tested. Release from PI was even complete, which extends on the prior work that did not include a no-PI condition. The results on response latencies also go beyond the prior work by showing reduced response latencies for the target items when the nontarget lists were tested after study; latencies in the testing condition were even indistinguishable from those in the no-PI condition, which indicates a perfect release from PI. The release effect on latencies was again driven by an effect on subsequent-response latencies, suggesting an effect on retrieval from the search set. Our results on release from PI are consistent with the view that testing the nontarget lists after study enhances segregation between nontarget and target lists and thus reduces mental search set size when target items are recalled. This proposal was already suggested in prior work (Szpunar et al., 2008), but without testing it directly. Experiment 2 is the first experiment to demonstrate the adequacy of this view.

Experiment 3

Experiment 3 employed a 2-list paradigm and a context-change task to examine buildup of PI and release from PI. Like the previous experiments, the experiment included three experimental conditions. In the context-change and no-context-change conditions, participants studied a nontarget list and subsequently a target list and, between study of the two lists, performed a mental imagination task (context-change condition) or counted backwards from a three-digit number (no-context-change condition). The mental imagination task (i.e., imagining being back in one's childhood home; e.g., Pastötter & Bäuml, 2007; Sahakyan & Kelley, 2002) was similar in content to daydreams, which are known to mentally transport people to another place or time (Delaney, Sahakyan, Kelley, & Zimmerman, 2010); the counting task, on the contrary, is known to induce no such mental context change (Klein, Shiffrin, & Criss, 2007). In the no-PI condition, participants studied the target list only, preceded by an unrelated distractor task. The no-context change condition served as the PI condition and the context change condition as the release-from-PI condition in the present experiment. After study of the target

list, in all three conditions memory for the items of this list was tested; both response totals and response latencies were measured.

On the basis of the results of the previous experiments and the prior work on context-dependent forgetting (e.g., Pastötter & Bäuml, 2007; Sahakyan & Kelley, 2002), we expected to find both buildup of PI and release from PI in this experiment. We expected to find reduced target recall in the PI-condition (no-context-change condition) relative to the no-PI condition, and enhanced target recall in the release-from-PI condition (context-change condition) relative to the PI-condition (no-context-change condition).

Regarding response latencies, we expected to find increased latencies in the PI-condition (no-context-change condition) relative to the no-PI condition. Similar to the previous experiments, we also expected reduced latencies in the release-from-PI condition (context-change condition) relative to the PI-condition (no-context-change condition). Again, both buildup of PI and release from PI should be mainly reflected in subsequent-response latencies and less, if at all, in first-response latencies. The expected results would indicate that, like with directed forgetting and interpolated testing, release from PI after context change can be mediated by a reduction in participants' search set size, so that, in response to the context change, participants are able to (largely) restrict their memory search to the target items.

Methods

Participants. Twenty-four healthy students at Regensburg University took part in the experiment on a voluntary basis. They received 7 Euros for their participation. The sample consisted of 19 females and 5 males. Their mean age was 23.62 years with a range of 20–28 years. All participants spoke German as their native language. They were tested individually.

Materials. Five lists of 12 items each were created by drawing 60 items from the pool of the 120 items that were generated for Experiment 1A, with mean item length and item frequency being held constant across lists. Two lists were randomly assigned to the context-change-condition (CC condition), two lists to the no-context-change condition (no-CC condition), and one list to the no-PI condition for each participant.

Design and procedure. The design and procedure were identical to Experiment 1A with three exceptions: The one exception was that, instead of presenting a forget or remember cue before target-list encoding, participants dealt with an imagination task (CC condition) or a backward counting task (no-CC condition). In the CC condition, participants were asked to mentally walk through their childhood home and tell details to the experimenter for 45 s; in the no-CC condition, participants counted backwards in steps of three from a random three digit number for 45 s. The distractor phase in the no-PI condition was prolonged to account for the context-change/backward-counting task. The second exception to Experiment 1A was that, in the present experiment, there was just a single experimental block containing the three experimental conditions, rather than two successive blocks as in Experiment

1A. Finally, the third exception to Experiment 1A was that, at test, both in the CC and the no-CC condition, the items of the nontarget list were tested as well. Nontarget recall occurred after participants had recalled the target items. The participants' responses on target and nontarget recall were recorded and analyzed in the same way like participants' responses on target recall in Experiments 1A and 1B.

Results

Response totals. Participants correctly recalled 65.62% of the target items in the CC condition, 56.94% in the no-CC condition, and 78.82% in the no-PI condition. An overall ANOVA of the three conditions (CC, no-CC, no PI) showed a significant effect, $F(2, 46) = 24.269$, $MSE = 0.012$, $p < 0.001$, $\eta_p^2 = 0.513$. Pairwise comparisons revealed that the difference of 21.88% in target list recall between the no-PI condition and the CC condition was reliable, $t(23) = 6.665$, $p < 0.001$, $d = 1.532$, reflecting the buildup of PI in the no-CC condition compared to the no-PI condition. The difference of 8.68% between the CC condition and the no-CC condition was significant as well, $t(23) = 2.687$, $p = 0.013$, $d = 0.649$, showing release from PI after a context change. The difference of 13.20% between the no-PI condition and the CC condition was also reliable, $t(23) = 4.452$, $p < 0.001$, $d = 0.877$, which points to an only partial release from PI after the context change. The mean rate of intrusions from the nontarget list during target recall was 4.55%, in both the CC condition and the no-CC condition.

Response latencies. Table 3 shows the first-response latencies of targt list recall. Mean first-response latencies for the target list were 1.31 s, 1.46 s, and 1.33 s for the CC condition, the no-CC condition, and the no-PI condition. An overall ANOVA of the three conditions (CC, no-CC, no-PI) revealed no significant differences, $F(2, 46) < 1$, suggesting that first-response latencies did not depend on condition.

Again, subsequent-response latencies were grouped into 5-s bins and plotted as a function of time (see Fig. 3). The parameter estimates of asymptotic percentage (N) revealed values of 56.52% for target list recall in the CC condition, 50.88% in the no-CC condition, and 70.56% in the no-PI condition. Again, corrected totals – 57.29% in the CC condition, 48.61% in the no-CC condition, and 70.49% in the no-PI condition – were very similar to the estimated values of N. This indicates that recall was close to asymptote in the current experiment.[2]

Estimated subsequent-response latencies for the target list were 6.97 s, 8.67 s, and 7.06 s for the CC condition, the no-CC condition, and the no-PI condition. The difference of 1.61 s between the no-PI condition and the no-CC condition was reliable, $t(20) = 2.176$, $p = 0.042$, demonstrating

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[2] While across all four experiments, the exponential accounts for nearly all of the variance in the response latency data, visual inspection of Figs. 1–3 suggests some small systematic deviation: the curve slightly underestimates the data points in the last third of the recall period, with subjects giving more late responses than predicted by the exponential. Because the deviation was extremely small and did not vary across conditions, it should not have affected conclusions.

Table 3
Response totals (i.e., percentage of recalled items) and response latencies (in seconds) of the target list and List 1 for Experiment 3 (standard errors in parentheses). VAF = variance accounted for by the exponential.

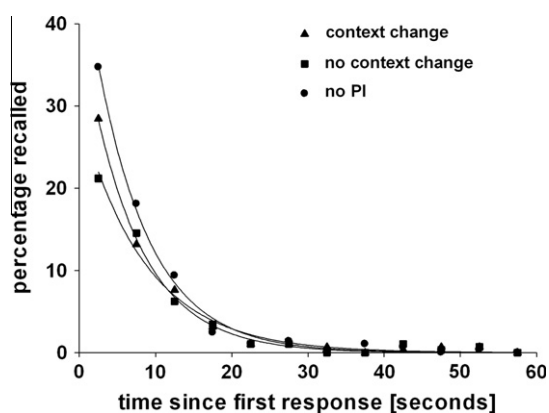|	Condition	% Recalled	First-response latency	Subsequent-response latency (τ)	VAF
Target list	Context change	65.62 (3.34)	1.31 (0.08)	6.97 (0.24)	0.99
	No context change	56.94 (5.08)	1.46 (0.21)	8.67 (0.67)	0.98
	No PI	78.82 (3.51)	1.33 (0.08)	7.06 (0.32)	0.99
List 1	Context change	46.53 (3.44)	3.54 (1.16)	7.86 (0.46)	0.99
	No context change	58.33 (5.33)	1.53 (0.17)	7.06 (0.47)	0.96

Fig. 3. Results of Experiment 3: Target recall – percentage of recalled items – for each 5-s bin in the context change (PI-release), the no-context change (PI), and the control (no-PI) condition together with the best fitting exponentials (PI = proactive interference). Latency is measured from the first response.

the buildup of PI in the no-CC condition. The difference of 1.70 s between the CC condition and the no-CC condition was also significant, $t(20) = 2.297$, $p = 0.033$, showing release from PI after the context change. The difference between the CC condition and the no-PI condition was not reliable, $t(20) < 1$, pointing to a complete release from PI.

Nontarget recall. Concerning the nontarget items of List 1, participants recalled significantly more items in the no-CC condition than the CC condition, $F(1,23) = 11.561$, $MSE = 0.082$, $p = 0.002$, $\eta_p^2 = 0.335$, reflecting typical context-dependent forgetting (e.g., Sahakyan & Kelley, 2002). Regarding response latencies, the two conditions did not differ in first-response latencies, $F(2,46) < 1$, and they did also not differ in subsequent-response latencies, $t(20) = 1.212$, $p = 0.240$ (see Table 3).

Discussion

The results of Experiment 3 replicate those of the previous experiments on buildup of PI by showing reduced response totals and increased response latencies for the

target list when a nontarget list was studied before target list encoding. Again, the effect on latencies was mainly driven by an effect on subsequent-response latencies but not on first-response latencies, suggesting an effect on retrieval from the search set rather than retrieval initiation.

Regarding release from PI, the results on response totals show enhanced response totals for the target items when, before study of the target list, an internal context change was induced (e.g., Sahakyan & Kelley, 2002), although, contrary to the previous experiments, the release from PI was not complete. The results on response latencies demonstrate reduced response latencies for the target items after the context change, with speed of recall being indistinguishable from that in the no-PI condition. The release effect on latencies was again driven by an effect on subsequent-response latencies, suggesting an effect on retrieval from the search set. Our results on release from PI are consistent with the view that changing the internal context between study of multiple lists enhances list segregation and thus reduces mental search set size when target items are recalled. Response latency results even suggest that, after the context change, search set can be about equally focused as in the no-PI condition.

In a recent study, Unsworth, Spillers, and Brewer (2012) also examined response latencies in a context change situation. However, whereas in this prior work a 1-list paradigm was used and it was examined whether a change in context after study of a list affects later recall of the list, in the present experiment the focus was on release from PI and a 2-list paradigm was employed to study the effect of inter-list context change on later recall of the second-list items. The present experiment thus goes beyond the prior work, demonstrating for the first time that release from PI in response to a context change is accompanied by a reduction in mental search set size.[3]

Additional analysis

Concerning first-response latencies, a fairly consistent numerical pattern emerged in all four experiments: the latencies increased slightly when PI built up, and they decreased slightly when PI was reduced (see Tables 1–3). When each experiment was analyzed separately, these effects were, at best, marginally significant (like in Experiments 1B and 2). To increase power, we examined the effect of PI and PI release on first-response latencies by analyzing the latencies simultaneously for all four experiments. A 3 (condition: release from PI, PI, no PI) x 4 (experiment: 1A, 1B, 2, 3) mixed design ANOVA revealed a main effect of condition, $F(2, 196) = 6.776$, $MSE = 1.120$, $p < 0.001$, $\eta_p^2 = 0.078$, no main effect of experiment, $F(3,98) = 1.134$, $MSE = 1.399$, $p = 0.340$, and no interaction between the two factors, $F(6,196) = 1.221$, $MSE = 1.120$, $p = 0.297$. Pairwise comparisons revealed a significant difference between the no-PI condition (1.34 s) and the PI

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[3] Using the 1-list paradigm, Unsworth and colleagues reported similar response latencies in the presence and the absence of a context change. Using the 2-list paradigm, the present results on List-1 recall replicate this finding, although numerically recall was more rapid in the absence than the presence of the context change (see Results of Experiment 3).

condition (1.80 s), $t(101) = 2.587$, $p = 0.011$, $d = 0.420$, showing an increase in latencies with PI; and they revealed a significant difference between the PI and release-from-PI conditions (1.36 s), $t(101) = 2.534$, $p = 0.013$, $d = 0.441$, reflecting a decrease in latencies with PI release. The difference of 0.02 s between the no-PI condition and the release-from-PI conditions was not reliable, $t(101) < 1$. These results suggest that there was a small effect of both PI and release from PI on first-response latencies and thus on the initiation phase of the retrieval process. This effect did not vary across experiments and thus did not depend on how exactly release from PI was induced.

General discussion

Buildup of PI

Consistent with prior work on buildup of PI, the results of the present series of experiments show that memory for a recently studied (target) list can be impaired by the preceding study of other (nontarget) list(s). Indeed, in each of the four experiments of this study, we found a reduction in response totals and an increase in response latencies for the target items if nontarget lists were studied previously; Experiments 1A and 3 showed this pattern in the presence of one preceding list, Experiments 1B and 2 in the presence of two preceding lists. In all four experiments, the increase in latencies was mainly due to an increase in subsequent-response latencies, suggesting that the study of prior lists increased the breadth of search at test. There was also a slight numerical effect on first-response latencies in each of the four experiments, which became significant only when the data of all four experiments were analyzed simultaneously. The effect suggests that the study of prior lists can also slow initiation of the retrieval process itself, although, relative to the increase in breadth of search, the influence is small.

While the present finding of PI in response totals is silent about whether retrieval or encoding processes mediate PI, the finding of PI in response latencies supports a retrieval account of PI. Because mean response latency is a sensitive index of the size of participants' mental search set, the results are consistent with the view that, in the presence of preceding nontarget lists, participants are unable to restrict their memory search to the target list and instead extend their search to items from the previously studied lists (e.g., Wixted & Rohrer, 1993). This interpretation is in line with the temporal discrimination theory of PI, according to which PI is caused by a failure to distinguish items from the most recent target list from items that appeared on the earlier nontarget lists (Baddeley, 1990; Crowder, 1976).

Prior work showed that, as predicted by McGill's (1963) random search model, mean latency (τ) depends linearly on search set size. For instance, Rohrer and Wixted (1994) let subjects study lists of three, six, and nine items and found mean latency to roughly double (triple) if the number of items in the mental search set doubled (tripled; for related results, see Wixted, Ghadisha, & Vera, 1997). In the present experiments, mean latency did not double or

even triple if participants studied one or two nontarget lists in addition to the target list. Instead, mean latencies increased between 15% (e.g., Experiment 1A; one nontarget list) and 25% (e.g., Experiment 1B; two nontarget lists), indicating that not all previously studied nontarget items were part of the search set. The finding suggests that study of an additional separate list of equal length does not increase latencies to the same extent than doubling the number of items within a list, indicating that separate list membership reduces interference and thus reduces latencies. The finding fits with prior work, showing only moderate intrusion errors from the wrong list(s) when multiple lists are studied (e.g., Pastötter & Bäuml, 2007; Sahakyan & Kelley, 2002), and it fits with the present result of only moderate intrusion rates from the nontarget list during target list recall (see Experiments 1–3).

Release from PI

The results of the present series of experiments show that a number of techniques can be applied to reduce or even cancel the PI effect, enabling participants to largely restrict their memory search to the target list. Across four experiments we showed that directed forgetting of nontarget material, the interpolated testing of the nontarget material, and a change in internal context between prior nontarget and subsequent target encoding reduced the PI effect. All three techniques led to an increase in response totals and a reduction in response latencies for the target items, inducing response totals that in three of the four experiments were indistinguishable from the no-PI condition, and inducing latencies that in all four experiments were indistinguishable from the no-PI condition.

In parallel to buildup of PI, release from PI in response latencies was mainly due to a decrease in subsequent-response latencies, suggesting that the study of prior lists affected the breadth of search at test. In parallel to buildup of PI, there was also an effect on first-response latencies in the single experiments, which became significant only when the results of all four experiments were analyzed simultaneously. The effect in first-response latencies suggests that release from PI does not only reduce breadth of search but accelerates initiation of the retrieval process itself. This holds while the effect on retrieval initiation is much smaller than the effect on breadth of search.

The results regarding buildup of PI support the view that reduced temporal discrimination between nontarget and target lists plays a critical role in buildup of PI. Analogously, the results regarding release from PI indicate that enhanced discrimination between nontarget and target lists plays a critical role in release from PI. Indeed, directed forgetting, interpolated testing, and context change induced a more focused memory search, making it easier for participants to distinguish items from the most recent target list from items that appeared on the earlier nontarget lists, relative to the PI conditions. Both buildup of PI and release from PI thus seem to affect search set size, adding nontarget items to the search set when PI is built up and eliminating nontarget items from the search set when PI is reduced. These results support the view that retrieval

processes, and particularly discrimination processes, play a critical role in buildup of PI and release from PI.

Release from PI with different methods but similar results

The results of the present study as well as the results from prior work (e.g., Bjork, 1970; Sahakyan & Kelley, 2002; Szpunar et al., 2008) demonstrate very similar effects of directed forgetting, interpolated testing, and context change on release from PI, both in terms of response totals and response latencies. This parallel between the three techniques holds while the techniques differ in their memorial effects on the previously studied nontarget items. Indeed, while directed forgetting and context change typically impair later recall of the preceding nontarget material (e.g., Geiselman et al., 1983; Sahakyan & Kelley, 2002), the testing of the preceding nontarget material enhances its later recall (e.g., Pastötter et al., 2011; Szpunar et al., 2008). Moreover, arguably, recall impairment of nontarget material in directed forgetting and context-dependent forgetting may be triggered by different mechanisms, inhibitory processes in the one case (directed forgetting; e.g., Geiselman et al., 1983) and noninhibitory processes in the other (context change; e.g., Sahakyan & Kelley, 2002). Apparently, techniques with different memorial consequences for previously studied (nontarget) information can show very similar memorial consequences for subsequently studied (target) information.

The results of Experiments 1A, 1B, and 2, which examined the effects of directed forgetting and interpolated testing on PI release, showed a complete release from PI, both in terms of response totals and response latencies. The results thus indicate that both a forget cue and the testing of prior lists can completely cancel the interference that arises from the study of prior lists. In contrast, the results of Experiment 3, which examined the effects of context change on PI release, showed a complete elimination of PI in terms of latencies, but only partial release from PI in terms of response totals. This finding may point to a difference in PI release between context change on the one hand and directed forgetting and interpolated testing on the other.[4] However, alternative explanations arise as well. When comparing results between Experiment 1A and Experiment 3, which both used a 2-list paradigm, quite different response totals arise in the no-PI condition, whereas nearly identical response totals arise in the PI and release-from-PI conditions (see Tables 1 and 3). The conclusion on whether directed forgetting and context change differ in amount of release from PI thus depends on whether response totals in the release-from-PI condition is compared with response totals in the PI condition, or with response totals in the no-PI condition. Obviously, future work is required to address the

issue in more detail and examine whether release from PI varies with the technique employed to induce the release.

Release from PI: retrieval or encoding?

Buildup of PI has repeatedly been suggested to be mediated by retrieval processes, as, for instance, reflected in temporal discrimination theory (Baddeley, 1990; Crowder, 1976; Wixted & Rohrer, 1993). And, indeed, the demonstrated detrimental effects of the study of prior lists on response latencies of a subsequently studied list support the view of a critical role of retrieval processes in this form of interference. Similarly, the present results on release from PI suggest that retrieval processes also play a critical role in release from PI, demonstrating beneficial effects of directed forgetting, interpolated testing, and context change on the latencies of a subsequently studied list. These results converge on the view that retrieval processes play an important role in both buildup of PI and release from PI.

The present experiments exclusively focused on the role of retrieval processes in PI and PI release, being silent on the possible additional involvement of encoding processes. The results from prior work, however, strongly suggest that not only retrieval processes but also encoding processes can contribute to PI and PI release. Corresponding evidence arises from both behavioral work (directed forgetting; context change; e.g., Pastötter & Bäuml, 2010; Sahakyan & Delaney, 2003, 2005) and neurocognitive work (directed forgetting; context change; interpolated testing; e.g., Bäuml, Hanslmayr, Pastötter, & Klimesch, 2008; Pastötter et al., 2008; Pastötter et al., 2011). Together with the results from the present study, these findings indicate that, in general, both encoding and retrieval processes may contribute to PI and PI release, an indication that also has direct implications for theoretical accounts of directed forgetting, interpolated testing, and context change.

The suggestion that both encoding and retrieval processes contribute to PI release also agrees with the results of two more recent studies on release from PI. In the one study, Jacoby et al. (2010) showed that participants' experience with PI can modulate PI. Using paired associates as item material, participants were given two rounds of experience with PI. Experience with PI turned out to influence participants' encoding of the target material in the second round, and thus to reduce PI. A subsequent study (Wahlheim & Jacoby, 2011) extended the prior finding by showing that both encoding and retrieval can change with PI experience. Wahlheim and Jacoby found that experience-induced release from PI was accompanied by reduced reactivation of the nontarget item while the target item was produced, a finding that may parallel the present result of reduced search set size with release from PI.

Arguably, also the present results might include evidence for the involvement of encoding processes in PI release. Indeed, while response latencies are a good index of search set size, there is evidence that search set size is not the only factor that may influence response latencies. Although both study time and number of study trials have been found to leave response latencies unaffected (e.g., Rohrer, 1996; Wixted et al., 1997), relational processing of list items has been reported to affect latencies, with

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[4] For Experiment 1A, this is also true when analysis is restricted to the first experimental block. In this experiment, each participant ran two successive blocks, with each block including a no-PI, remember, and forget condition (see Methods of Experiment 1A). Although recall levels increased from the first to the second block, $p = .001$, thus replicating a recent finding by Pastötter et al. (2012), this effect did not vary with condition, $F(2, 22) < 1$. Consistently, also in the first experimental block, recall in the no-PI condition did not differ from recall in the forget condition, $p = .151$.

more rapid recall of list items with orienting tasks promoting category sorting than with item-specific processing tasks (Burns & Schoff, 1998).[5] If a forget cue, interpolated testing, and context change initiated such categorization processes in subjects' encoding, the observed faster recall of target items in the present experiments might include effects of encoding. However, to date no evidence for such categorization processes in response to a forget cue, interpolated testing, or context change has been reported. Rather, the results from recent work suggest that encoding in such situations mimics encoding of the initially studied list(s) (directed forgetting: Pastötter & Bäuml, 2010; context-dependent forgetting: Pastötter et al., 2008; interpolated testing: Pastötter et al., 2011), thus indicating that the observed reductions in latency that accompany release from PI reflect the influence of retrieval rather than the influence of encoding.

Conclusions

Across four experiments we showed that both buildup of PI and release from PI affect participants' search set size at test. In all four experiments the prior study of nontarget material increased response latency of subsequently studied target material, which points to an increase in participants' search set size when PI arises. Analogously, in all four experiments response latencies for the target items decreased when PI was reduced – in response to a forget cue, interpolated testing, or a context change. These results suggest more focused memory search, indicating that, with release from PI, the previously studied nontarget items are largely eliminated from the search process. The results provide direct evidence for a critical role of retrieval processes in PI release.

References

Anderson, M. C., & Neely, J. H. (1996). Interference and inhibition in memory retrieval. In E. L. Bjork & R. A. Bjork (Eds.), *Memory: Handbook of perception and cognition* (2nd ed., pp. 237–313). San Diego, CA: Academic Press.

Baddeley, A. (1990). *Human memory. Theory and practice*. London: Lawrence Erlbaum Associates.

Bäuml, K.-H., Hanslmayr, S., Pastötter, B., & Klimesch, W. (2008). Oscillatory correlates of intentional updating in episodic memory. *NeuroImage, 41*, 596–604.

Bäuml, K.-H., Pastötter, B., & Hanslmayr, S. (2010). Binding and inhibition in episodic memory – Cognitive, emotional, and neural processes. *Neuroscience & Biobehavioral Reviews, 34*, 1047–1054.

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.

Bjork, E. L., & Bjork, R. A. (1996). Continuing influences of to-be-forgotten information. *Consciousness and Cognition, 5*, 176–196.

Bjork, R. A. (1970). Positive forgetting: The noninterference of items intentionally forgotten. *Journal of Verbal Learning and Verbal Behavior, 9*, 255–268.

Bjork, R. A. (1989). Retrieval inhibition as an adaptive mechanism in human memory. In H. L. Roediger & F. I. M. Craik (Eds.), *Varieties of memory and consciousness: Essays in honour of Endel Tulving* (pp. 309–330). Hillsdale, NJ: Erlbaum.

Bousfield, W. A., & Sedgewick, C. H. W. (1944). An analysis of sequences of restricted assoiciative responses. *Journal of General Psychology, 30*, 149–165.

Burns, D. J., & Schoff, K. M. (1998). Slow and steady often ties the race: Effects of item-specific and relational processing on cumulative recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 1041–1051.

Crowder, R. G. (1976). *Principles of learning and memory*. New York: John Wiley & Sons.

Delaney, P., Sahakyan, L., Kelley, C. M., & Zimmerman, C. (2010). Remembering to forget: The amnesic effect of daydreaming. *Psychological Science, 21*, 1036–1042.

Dillon, R. F., & Thomas, H. (1975). The role of response confusion in proactive interference. *Journal of Verbal Learning and Verbal Behavior, 14*, 603–615.

Duyck, W., Desmet, T., Verbeke, L., & Brysbaert, M. (2004). Wordgen: A tool for word selection and non-word generation in Dutch, German, English, and French. *Behavior Research Methods, Instruments and Computers, 36*, 488–499.

Geiselman, R. E., Bjork, R. A., & Fishman, D. (1983). Disrupted retrieval in directed forgetting: A link with posthypnotic amnesia. *Journal of Experimental Psychology: General, 112*, 58–72.

Herrmann, D. J., & Pearle, P. M. (1981). The proper role of clusters in mathematical models of continuous recall. *Journal of Mathematical Psychology, 24*, 139–162.

Jacoby, L. L., Wahlheim, C. N., Rhodes, M. G., Daniels, K. A., & Rogers, C. S. (2010). Learning to diminish the effects of proactive interference: Reducing false memory for young and older adults. *Memory & Cognition, 38*, 820–829.

Klein, K. A., Shiffrin, R. M., & Criss, A. H. (2007). Putting context in context. In J. S. Nairne (Ed.). *The foundations of remembering: Essays in honor of Henry L. Roediger* (Vol. III, pp. 171–190). New York: Psychology Press.

MacLeod, C. M. (1998). Directed forgetting. In J. M. Golding & C. M. MacLeod (Eds.), *Intentional forgetting: Interdisciplinary approaches* (pp. 1–57). Mahwah, NJ: Erlbaum.

McGill, W. J. (1963). Stochastic latency mechanism. In R. D. Luce, R. R. Bush, & E. Galanter (Eds.). *Handbook of mathematical psychology* (Vol. 1, pp. 309–360). New York: Wiley.

Morrison, D. G. (1979). An individual differences pure extinction process. *Journal of Mathematical Psychology, 19*, 307–315.

Pastötter, B., & Bäuml, K.-H. (2007). The crucial role of postcue encoding in directed forgetting and context-dependent forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*, 977–982.

Pastötter, B., & Bäuml, K.-H. (2010). Amount of postcue encoding predicts amount of directed forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*, 54–65.

Pastötter, B., Kliegl, O., & Bäuml, K.-H. T. (2012). List-method directed forgetting: The forget cue improves both encoding and retrieval of postcue information. *Memory & Cognition, 40*, 861–873.

Pastötter, B., Bäuml, K.-H., & Hanslmayr, S. (2008). Oscillatory brain activity before and after an internal context change – Evidence for a reset of encoding processes. *NeuroImage, 43*, 173–181.

Pastötter, B., Schicker, S., Niedernhuber, J., & Bäuml, K.-H. T. (2011). Retrieval during learning facilitates subsequent memory encoding. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*, 287–297.

Rohrer, D. (1996). On the relative and absolute strength of a memory trace. *Memory & Cognition, 24*, 188–201.

Rohrer, D., Salmon, D. P., Wixted, J. T., & Paulsen, J. S. (1999). The disparate effects of Alzheimer's disease and Huntington's disease on semantic memory. *Neuropsychology, 13*, 381–388.

Rohrer, D., & Wixted, J. T. (1994). An analysis of latency and interresponse time in free recall. *Memory & Cognition, 22*, 511–524.

Rohrer, D., Wixted, J. T., Salmon, D. P., & Butters, N. (1995). Retrieval from semantic memory and its implications for Alzheimer's disease. *Journal of Experimental Psychology: Human Learning and Memory, 21*, 1127–1139.

Sahakyan, L., & Delaney, P. F. (2003). Can encoding differences explain the benefits of directed forgetting in the list method paradigm? *Journal of Memory and Language, 48*, 195–206.

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[5] Burns and Schoff (1998) demonstrated this effect by employing written free recall and conducting a minute-by-minute analysis of cumulative recall scores, which required subjects to draw a line under the last word recalled after each minute of recall; already recalled items thus could be used as retrieval cues for recall of the remaining items. In contrast, in the present study recall was orally, the voice onset of each single recalled item was determined, and latencies were analyzed using noncumulative latency functions. This procedure allows very exact analysis of response latencies and reduces the possibility that subjects use already recalled items as retrieval cues for recall of the remaining items (e.g., Wixted & Rohrer, 1993; Wixted et al., 1997).

Sahakyan, L., & Delaney, P. F. (2005). Directed forgetting in incidental learning and recognition testing: Support for a two-factor account. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 789–801.

Sahakyan, L., & Foster, N. L. (2009). Intentional forgetting of actions: Comparison of list-method and item-method directed forgetting. *Journal of Memory and Language, 61*, 134–152.

Sahakyan, L., & Kelley, C. M. (2002). A contextual change account of the directed forgetting effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*, 1064–1072.

Spillers, G. J., & Unsworth, N. (2011). Are the costs of directed forgetting due to failures of sampling or recovery? Exploring the dynamics of recall in list-method directed forgetting. *Memory & Cognition, 39*, 303–411.

Szpunar, K. K., McDermott, K. B., & Roediger, H. L. III, (2008). Testing during study insulates against the buildup of proactive interference. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*, 1392–1399.

Tulving, E., & Watkins, M. J. (1974). On negative transfer: Effects of testing one list on recall of another. *Journal of Verbal Learning and Verbal Behavior, 13*, 181–193.

Underwood, B. J. (1957). Interference and forgetting. *Psychological Review, 64*, 49–60.

Unsworth, N., Spillers, G. J., & Brewer, G. A. (2012). Dynamics of context-dependent recall: An examination of internal and external context change. *Journal of Memory and Language, 66*, 1–16.

Vorberg, D., & Ulrich, R. (1987). Random search with unequal search rates: Serial and parallel generalizations of McGill's model. *Journal of Mathematical Psychology, 31*, 1–23.

Wahlheim, C. N., & Jacoby, L. L. (2011). Experience with proactive interference diminishes its effects: Mechanisms of change. *Memory & Cognition, 39*, 185–195.

Weinstein, Y., McDermott, K. B., & Szpunar, K. K. (2011). Testing protects against proactive interference in face-name learning. *Psychonomic Bulletin & Review, 18*, 518–523.

Wixted, J. T., Ghadisha, H., & Vera, R. (1997). Recall latency following pure- and mixed-strength lists: A direct test of the relative strength model of free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 523–538.

Wixted, J. T., & Rohrer, D. (1993). Proactive interference and the dynamics of free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 1024–1039.

Wixted, J. T., & Rohrer, D. (1994). Analyzing the dynamics of free recall: An integrative review of the empirical literature. *Psychonomic Bulletin & Review, 1*, 89–106.