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How Delay Influences Search Processes at Test

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Delay-induced forgetting refers to the finding that memory for studied material typically decreases as the delay between study and test is increased. The results of 3 experiments are reported designed to examine whether this form of forgetting is primarily caused by interference effects or contextual drift effects when people engage in neutral distractor tasks during the delay. Response latency analysis was used to contrast predictions of the interference and the contextual drift view of the forgetting. The results demonstrated that prolonged delay between study and test of a list of items reduced both recall rates and mean response latencies. Because mean latency provides a reliable index of the size of people's mental search set at test, the findings suggest that prolonged delay impeded people's ability to include studied items into the search set. The results also showed that (a) mental context reinstatement before test can eliminate this effect, and (b) younger and older adults differ in their susceptibility to interference effects but show comparable delay-induced forgetting. The findings indicate that, with neutral distractor tasks, delay-induced forgetting is primarily mediated by contextual drift. Such drift reduces people's mental search set at test and, thus, decreases both recall rates and response latencies.

Keywords: delay, forgetting, contextual drift, interference, response latencies

Many of the smaller and greater challenges of our daily lives require the ability to retrieve previously encoded information, like when we attempt to recall our current computer password, the name of a particular student, or where we parked our car earlier today. The probability that such retrieval attempts fail often increases as the delay between encoding and recall of a particular information is increased (Ebbinghaus, 1885; Slamecka & McElree, 1983). Particularly two explanations for such delay-induced forgetting have been proposed in the literature. The one explanation originates from classic interference theory and assumes that, during the delay, further information is encoded that, at retrieval, interferes with the target information and, thus, reduces target recall (Postman, 1961; Wixted, 2005). The other explanation is based on the view that contextual drift mediates the forgetting. When we encode material, we also store information about the temporal context in which the material is encountered (Howard & Kahana, 2002; Raaijmakers & Shiffrin, 1981). Because temporal context drifts slowly with delay (Bower, 1972; Estes, 1955), the context at test often differs from the context at study after prolonged delay, which, following Tulving's (1972) encoding specificity principle, can impair recall of the target information.

Interference-based and context-based forgetting differ in the search processes presumed to underlie the forgetting. On the basis of the view that interference mediates delay-induced forgetting, delay can influence search processes through the encoding of additional nontarget material during the delay. Such additional encoding can affect recall of the initially studied target material by inducing retrieval competition at test, a property of the retrieval process that is supposed to be intrinsic to retrieval (Anderson, 1981; Raaijmakers & Shiffrin, 1981). Indeed, because of retrieval competition, not only the target items but also some of the nontarget material encoded during the delay may be coactivated at test and be included into the mental search set. The induced increase in search set size then makes the memory search for the target items more difficult and impairs target recall (e.g., Wixted & Rohrer, 1993; for a discussion of the possible role of other interference-based processes in delay-induced forgetting, see General Discussion).

On the basis of the view that contextual drift mediates delay-induced forgetting, there are at least two possibilities how delay can influence search processes. The one possibility is that prolonged delay reduces the strength of the study items in memory. This hypothesis, which reflects a prominent idea in the delay literature and is referred to as the reduced-strength hypothesis in the following, assumes that the reduced contextual overlap between study and test after longer delay attenuates the associative strength between the study items and the retrieval cues used at test, so that some of the study items may no longer be recovered into consciousness and be successfully recalled (Mensink & Raaijmakers, 1988). The second possibility is that, after prolonged delay, participants include a smaller number of study items into the search set than after short delay. The critical assumption of this hypothesis is that, because of the reduced contextual overlap between study and test after longer delay, participants use less efficient retrieval cues that activate fewer of the study items than after short delay. Sampling may, therefore, occur from a reduced search set, thereby lowering the number of recallable items. This view has barely been considered in the memory literature (for an

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exception, see Unsworth, Brewer, & Spillers, 2011) and is referred to as the reduced-search-set hypothesis in the following.

If contextual drift mediated delay-induced forgetting, the size of the mental search set should, therefore, be reduced after delay—when a smaller number of study items was activated than after short delay (reduced-search-set hypothesis)—or be unaffected by delay—when the memory strength of the study items was reduced without influencing search set size (reduced-strength hypothesis). In contrast, if interference mediated delay-induced forgetting, search set size should increase with delay because of coactivation of the material that was encoded during the delay. With these different expectations on search processes after delay, it was the goal of the present study to examine how delay influences search processes, providing information on whether delay-induced forgetting is mainly because of interference or context drift. In the latter case, results may additionally indicate whether the forgetting is because of reduced item strength, a reduction in search set size, or both.

Search Processes and Response Latencies

Results from numerous studies have shown that interference-based forgetting not only comes with reduced recall but also with slowed recall. Using response latency analysis, Wixted and Rohrer (1993), for instance, showed that prior study of nontarget material not only decreased recall rates for more recently studied target material, but also increased the recalled material's mean response latencies (see also Bäuml & Kliegl, 2013; Kliegl, Pastötter, & Bäuml, 2015; Unsworth, Brewer, & Spillers, 2013). Because mean response latency can be regarded an index of participants' mental search set size (McGill, 1963; Wixted & Rohrer, 1993), the observed increase in response latencies indicates that, at test, some of the nontarget material became coactivated and included into the search set, which is consistent with the general view that interference increases search set size at test. Thus, on the basis of the interference view of delay-induced forgetting, delay should not only decrease recall rates but also slow the recall process.

Like a delay-induced increase in interference level, delay-induced contextual drift should also reduce recall rates (Tulving, 1972), but it should not slow the retrieval process. On the basis of the reduced-strength hypothesis, for instance, the induced contextual drift is assumed to reduce the memory strength of the study items, but to not affect the size of the search set at test. As a result, response latencies should not be much affected by the length of the delay interval between study and test (Mensink & Raaijmakers, 1988; Rohrer, 1996). On the basis of the reduced-search-set hypothesis, participants may not be able to generate retrieval cues at test that reactivate as many of the study items than after short delay. Such inability should lead to reduced search set size and, therefore, reduced response latencies (Rohrer, 1996; Unsworth et al., 2011). Thus, across different delay intervals, analysis of response latencies may inform us about whether the delay-induced forgetting is caused mainly by interference or context drift, and in the latter case, whether it is because of reduced item strength or a reduction in search set size at test.

Prior Work on Delay-Induced Forgetting and Response Latencies

Prior work on the effects of prolonged delay on retrieval speed is sparse, and the results are mixed. To our knowledge, only a single study has directly investigated the effect of prolonged delay on response latencies. In this study, Unsworth et al. (2011) applied a running paired-associate task, in which participants studied cue-target pairs (e.g., basket - rent), and, after delays that ranged between 0 min and about 8 min, memory for the target word was tested (e.g., basket - ___). During these delays, participants were presented with additional, to-be-studied paired associates. Results for the initially studied pairs showed both a reduction in recall rates and an increase in response latencies with delay. The observed increase in latencies suggests that participants included some of the intervening material into the search set; thus, increasing search set size and decreasing recall rates. The finding is consistent with the interference hypothesis, suggesting that coactivation of nontarget items can underlie delay-induced forgetting.

A further study addressed the issue of how a contextual mismatch between study and test affects response latencies. In this study, Unsworth, Spillers, and Brewer (2012) held delay between study and test constant and experimentally induced contextual change. Participants studied a list of unrelated items and context change between study and test was induced by either having participants tested in a different room as the material was learned in (Experiment 1), or by engaging them in an imagination task before the test, in which they were asked to draw their childhood home (Experiment 2). Results showed that context change reduced recall rates, but it did not affect response latencies. On the basis of the view that delay induces context drift, these results favor the reduced-strength hypothesis over the reduced-search-set hypothesis of delay-induced forgetting, indicating that prolonged delay may reduce the memory strength of the studied items. Together, the results of the two studies may suggest that delay per se does not influence latencies, but delay can lead to an increase in latencies if interfering material is encoded during the delay. Delay may, therefore, influence search processes either by increasing search set size or by reducing studied items' memory strength.

However, caution is warranted before drawing firm conclusions from this prior work. First, while context change as, for instance, induced by an imagination task during short retention interval may basically do similar things as contextual drift during prolonged delay, prolonged delay may induce a higher level of context drift than imagination tasks and, thus, lead to novel and more detailed insights into how context drift influences search processes. Second, no prior study has yet examined the search processes underlying delay-induced forgetting when longer neutral retention intervals are used. Neutral retention intervals are quite common in both the classic and the more recent delay-induced forgetting literature (Abel & Bäuml, 2017; Carpenter, 2011; Divis & Benjamin, 2014; Ebbinghaus, 1885; Roediger & Karpicke, 2006; Slamecka & McElree, 1983) and refer to tasks in which, during the delay between study and test, participants are engaged in distractor tasks that are unrelated to the study material, like working on counting tasks or simple arithmetic tasks. The single prior study that analyzed search processes in delay-induced forgetting to date (Unsworth et al., 2011) used retention intervals that were filled with the learning of further material and, thus, were designed to induce high levels of interference at test.

The Present Study

The goal of the present study was to examine search processes in delay-induced forgetting when the delay interval is filled with neutral distractor tasks. The results from a series of three experiments are reported, which indicate whether, with such neutral delays, the forgetting is caused by increased interference at test, or rather is mediated by contextual drift. In the latter case, prolonged delay could reduce the studied items' memory strength, or reduce search set size at test. Delay intervals of varying length were used in the single experiments. Encoding of interfering material was minimized during delay by engaging participants in a series of unrelated distractor tasks. Using such distractor tasks, it was examined (a) how prolonged delay influences recall rates and response latencies, and (b) how, after delay, mental reinstatement of study context influences the two memory measures. In addition, the effects of interference and delay were directly compared within a single, final experiment, including both younger and older adults as participants.

Experiment 1 examined the effects of prolonged delay on recall rates and response latencies using three delay intervals of different length between study and test. Because delays were filled with neutral distractor tasks in this experiment, we expected delay-induced forgetting that was largely mediated by contextual drift and much less, if at all, by interference. Therefore, delay should reduce the items' memory strength, that is, not influence response latencies (reduced-strength hypothesis), or reduce search set size at test, that is, decrease response latencies (reduced-search-set hypothesis). To anticipate the results, we found delay to decrease both recall rates and response latencies, which is consistent with the view that, at test, search set size was reduced.

Experiment 2 examined contextual drift processes supposedly underlying delay-induced forgetting in more detail by including a further condition after delay, in which participants, immediately before recall started, mentally reinstated the study context. Such reinstatement should reduce the delay-induced mismatch between study and test contexts. On the basis of the reduced-search-set hypothesis, the reinstatement should, therefore, increase the number of studied items included in the search set and increase both recall rates and response latencies. The results replicated those of Experiment 1, showing reduced recall rates and reduced response latencies after delay when there was no context reinstatement. In contrast, when context reinstatement took place, both recall rates and response latencies increased relative to the no context reinstatement condition.

On the basis of the results of Experiments 1 and 2, which indicated context drift as the major cause of delay-induced forgetting with neutral retention intervals, Experiment 3 directly compared the effects of (proactive) interference and prolonged delay at test, in both younger and older adults. While in younger adults, both proactive interference and prolonged delay should reduce recall rates, proactive interference should increase response latencies (Bäuml & Kliegl, 2013; Wixted & Rohrer, 1993), whereas prolonged delay should decrease response latencies (present Experiments 1 and 2). Because older adults are known to be more susceptible to the effects of proactive interference than younger adults (Hasher, Chung, May, & Foong, 2002; Lustig, May, & Hasher, 2001), we expected to find more pronounced proactive interference effects in older adults, in both recall rates and latencies. The experiment will provide information on whether such increased interference susceptibility is accompanied by increased susceptibility to contextual drift effects in older age.

Experiment 1

Experiment 1 examined how prolonged delay between study and test affects recall rates and response latencies. Participants studied a list of unrelated items that was tested after a delay of 1, 10, or 30 min. Because the delay intervals were filled with neutral distractor tasks, we expected the delay to hardly influence the interference level at test and, thus, not to increase response latencies. Rather, we expected the delay to induce mainly contextual drift and, thus, to either reduce the studied items' memory strength (reduced-strength hypothesis) or reduce search set size at test (reduced-search-set hypothesis). If the contextual drift reduced items' memory strength, delay should leave latencies largely unaffected; if the contextual drift reduced search set size at test, delay should decrease response latencies.

Method

Participants. Eighty-one healthy students (18–32 years; M = 22.7 years) at Regensburg University took part in the experiment on a voluntary basis. Sample size was based on prior work examining response latencies in free-recall tasks (Bäuml & Kliegl, 2013; Unsworth et al., 2013). All participants spoke German as their native language. They were tested individually.

Materials. The study list consisted of 18 unrelated nouns of medium frequency that were drawn from the CELEX database using the Wordgen v1.0 software toolbox (Duyck, Desmet, Verbeke, & Brysbaert, 2004).

Design and procedure. The experiment was composed of three conditions: the 1-, 10-, and 30-min delay conditions, with 27 participants in each of the single conditions. In each condition, participants studied a list of 18 items. Item order within lists was random for each participant. Each item was presented individually on a computer screen at a rate of 2.5 s per item. After study, all participants were asked to count backward from a three-digit number in steps of two for 60 s. In the 10-min-delay condition, participants additionally engaged in Raven's standard progressive matrices (Raven, Raven, & Court, 2000) task for 9 min. In the 30-min-delay condition, participants also engaged in the Raven task for 9 min (Task 1), but they subsequently were asked to solve spot-the-difference puzzles for 9 min (Task 2) and then to solve simple arithmetic tasks for 5 min (Task 3). Between Tasks 1 and 2, Tasks 2 and 3, and Task 3 and the test, there were 2-min intervals during each of which participants were engaged in a different imagination task for 2 min. In this task, participants were either asked to imagine (a) their parents' house and to mentally walk through it, or (b) the things they would like to do if they were invisible and did not have to take responsibility for their actions, or (c) being back on their last vacation and to remember and refeel the most beautiful moments as clearly as possible (Delaney, Sahakyan, Kelley, & Zimmerman, 2010; Sahakyan & Kelley, 2002). Participants were also asked to write down their imaginations. The three imagination tasks were used in random order. After the distractor phase, participants were given 90 s to remember as many items as possible from the study list in any order the participants wished.

The participants' answers at test 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 free computer software Audacity (Version 2.0.6, Softonic International S.L., Barcelona, Spanien), whereby the voice onset of each recalled item was manually located in the spectrogram (see Bäuml, Zellner, & Vilimek, 2005; Kliegl et al., 2015).

Measure of latency. A more detailed analysis of the recall process, which does not only analyze number of recalled items but also includes analysis of the time at which the single items are recalled within the test period (response latencies), shows that participants typically produce many items early in the test period and relatively few items later in the test period. Consistently, response latencies have been found to be well described by the two-parameter exponential,

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

where $r(t)$ represents the number of items recalled within 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).

For each of the three delay conditions (control, 10 min, and 30 min), response latencies were analyzed. Prior work on response latency analysis often distinguished between first response and subsequent response latency (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 latencies 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.

Subsequent response latencies were grouped into 5-s bins and exponential functions were fitted to the response latency functions of each condition. The two parameters N—representing asymptotic recall—and τ - representing the mean latency of those N items—were derived from fitting the exponential to the data. The best fitting exponentials were determined by least square minimization. Using the asymptotic *SE* 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

Figure 1a shows recall rates (left panel) and mean response latencies (τ; right panel) for the control, 10-min-delay, and 30-min-delay conditions. Figure 2a shows response latency distributions and best-fitting exponential functions for the three conditions.

Recall rates. Regarding recall rates, participants correctly recalled 61.9% of the items in the control condition, 49.6% of the

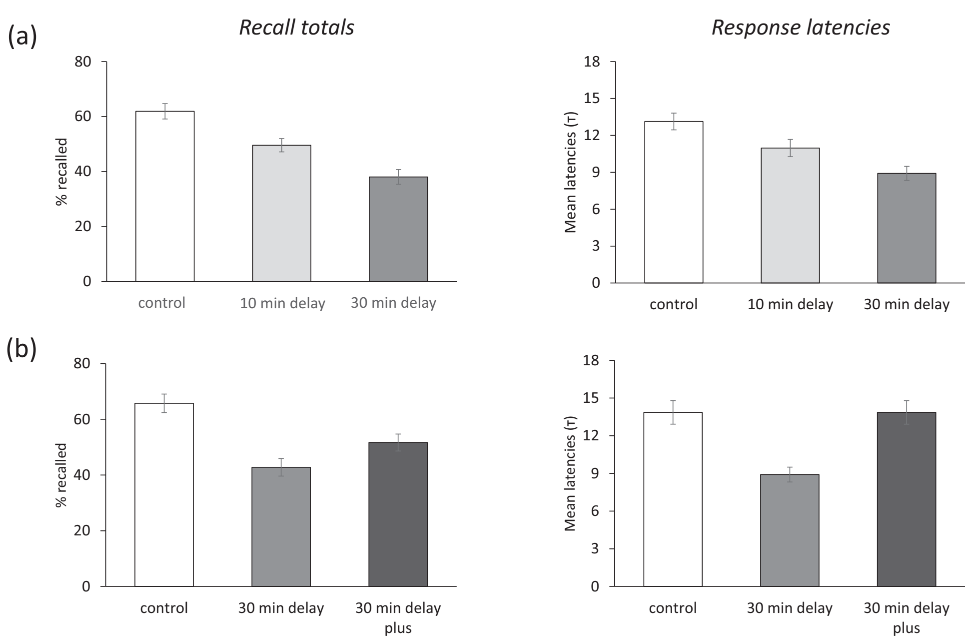

Figure 1. (a) Results of Experiment 1: Percentage recalled and mean response latencies (τ) for the control, 10-min-delay, and 30-min-delay conditions. Error bars represent *SE*s. (b) Results of Experiment 2: Percentage recalled and mean response latencies (τ) for the control, 30-min delay, and 30-min-delay-plus-reinstatement conditions.

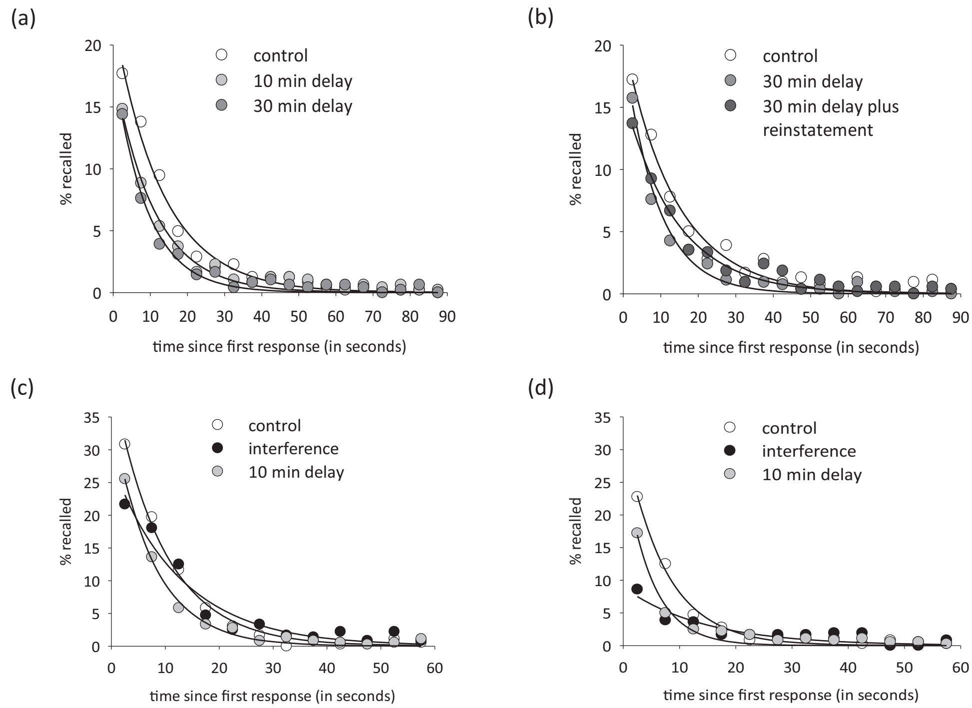

Figure 2. (a) Response latency distributions and best-fitting exponential functions for the control, 10-min-delay, and 30-min-delay conditions of Experiment 1. (b) Response latency distributions and best-fitting exponential functions for the control, 30-min-delay, and 30-min-delay-plus-reinstatement conditions of Experiment 2. (c) Response latency distributions and best-fitting exponential functions for younger adults in the control, interference, and 10-min-delay conditions of Experiment 3. (d) Response latency distributions and best-fitting exponential functions for older adults in the control, interference, and 10-min-delay conditions of Experiment 3.

items in the 10-min-delay condition, and 38.1% of the items in the 30-min-delay condition; thus, showing typical delay-induced forgetting. An overall analysis of variance (ANOVA) of the three conditions (control, 10-min-delay, and 30-min-delay) showed a significant effect of condition, $F(2, 78) = 19.654$, $MSE = 0.020$, $p < .001$, $\eta_p^2 = .335$. Pairwise comparisons revealed significant decreases in recall from the control to the 10-min-delay condition, $t(52) = 3.348$, $p = .002$, $d = 0.911$, and from the 10-min-delay to the 30-min-delay conditions, $t(52) = 3.085$, $p = .003$, $d = 0.839$.

Response latencies. First response latencies were 1.82 s in the control condition, 1.93 s in the 10-min-delay condition, and 2.52 s in the 30-min-delay condition. An overall ANOVA of the three conditions (control, 10-min-delay, and 30-min-delay) revealed no significant effect of condition, $F(2, 78) = 2.538$, $MSE = 1.501$, $p = .086$, $\eta_p^2 = .061$, suggesting that first response latencies did not depend much on condition.

Regarding subsequent response latencies, two-parameter exponentials were fit to the latency functions in the control, 10-min-delay, and 30-min-delay conditions. R^2 values for the best-fitting exponential were .99, .98, and .98 for the control, 10-min-delay, and 30-min-delay conditions, suggesting that the exponential accounted for a large portion of the variance in each condition (see Table 1). The parameter estimate of asymptotic total (N) revealed values of 58.4% for the control condition, 39.9% for the 10-min-delay condition, and 33.3% for the 30-min-delay condition. N is based on correct and incorrect subsequent responses only, whereas recall rates include first responses as well. Corrected rates, in which only the correct and incorrect subsequent responses were included—59.5% in the control condition, 44.9% in the 10-min-delay condition, and 37.9% in the 30-min-delay condition—were similar to the estimated values of N, indicating that recall was close to asymptote in both conditions.

The parameter estimates of mean latency (τ) were 13.1 s for the control condition, 11.0 s for the 10-min-delay condition, and 8.9 s for the 30-min-delay condition. The decrease of 2.1 s from the control to the 10-min-delay condition was reliable, $t(32) = 2.226$, $p = .033$, as was the decrease of 2.1 s from the 10-min to the 30-min delay condition, $t(32) = 2.277$, $p = .030$, suggesting that both recall rates and (subsequent) response latencies decreased with delay.

Discussion

The results of Experiment 1 show that recall rates were reduced in the 10-min-delay condition, relative to the control condition, and were reduced in the 30-min-delay condition, relative to the 10-min delay condition; thus, replicating typical delay-induced forgetting (Ebbinghaus, 1885; Slamecka & McElree, 1983). Response latency analysis showed that delay did not moderate first response latencies, suggesting that there was no substantial effect

Table 1
Percentage Recalled, First-Response Latencies, and Subsequent-Response Latencies for Experiments 1 and 2

Experiment	% recalled		First-response latency		Subsequent-response latency		VAF
	M	*SE*	*M*	*SE*	*M*	*SE*	
Control	61.93	2.79	1.82	.26	13.13	.68	.99
Experiment 1							
10-min-delay	49.59	2.41	1.93	.18	10.97	.70	.98
30-min-delay	38.07	2.67	2.52	.27	8.91	.57	.98
Control	65.74	3.31	1.56	.06	13.86	.94	.97
Experiment 2							
30-min-delay	42.78	3.17	1.63	.08	8.91	.59	.98
30-min-delay-plus-reinstatement	51.67	3.05	1.77	.06	13.86	.94	.97

Note. VAF = variance accounted for by the exponential; *M* = arithmetic mean.

on retrieval initiation. Similar to recall rates, however, subsequent response latencies were found to decrease in the 10-min-delay condition, relative to the control condition, and to further decrease in the 30-min-delay condition, relative to the 10-min delay condition, suggesting an effect of delay on retrieval from the search set. The findings on subsequent response latencies provide evidence for the involvement of contextual drift processes. In particular, they support the reduced-search-set hypothesis, which assumes that because of delay-induced contextual drift, participants use retrieval cues at test that do not have the capability of reactivating as many items as after short delay, which leads to a reduction in search set size with delay. In contrast, the findings do not support the hypothesis that the delay-induced forgetting was driven by increased interference at test, because, in this case, subsequent response latencies should have increased, rather than decreased, with delay.

The reduced-search-set hypothesis assumes a type of search failure where the items that are no longer part of the search set at test are still available in memory, but are temporarily inaccessible because participants are not able to generate the appropriate retrieval cues. Admittedly, the present finding that response latencies are reduced with prolonged delay is also consistent with the view that prolonged delay made some of the studied items unavailable. Indeed, trace-decay theory (Thorndike, 1914), a classic account of delay-induced forgetting, holds that memories can fade because of the mere passage of time, so that after prolonged delay, participants may include a subset of the study items only into their search set. Trace-decay theory, thus, differs from the reduced-search-set hypothesis by attributing delay-induced forgetting to a permanent loss of the study information, rather than a transient accessibility problem. Experiment 2 was designed to distinguish between the two views.

Experiment 2

The first goal of Experiment 2 was to replicate the central finding of Experiment 1, by showing that prolonged (neutral) delay is characterized by reduced recall rates as well as reduced response latencies. The second goal of the experiment was to determine whether the results of Experiment 1 originated from a decay of memory traces, or from a temporary inaccessibility of studied items. To address the first goal, we again manipulated the length of the delay interval between study and test. Participants studied a list of items that was tested after a delay of 1 min (control condition) or 30 min (30-min-delay condition). To address the second goal, we added a 30-min-delay-plus-reinstatement condition, in which there was also a 30-min delay between study and test (like in the 30-min-delay condition), but participants engaged in a context reinstatement task immediately before the test. This technique involves asking participants to mentally reinstate their original study environment, and has been demonstrated to diminish episodic forgetting in a number of experimental tasks (Jonker, Seli, & MacLeod, 2013; Sahakyan & Kelley, 2002; Smith, 1979; Wallner & Bäuml, 2017).

Following the results of Experiment 1, we expected that recall rates and response latencies would be reduced in the 30-min-delay condition, relative to the control condition, indicating that prolonged delay reduces search set size at test. Regarding the effects of the context reinstatement task before the test, two contrasting expectations may arise. On the basis of the reduced-search-set hypothesis, one may expect that the context reinstatement task increases the match between the study and test contexts, and should, thus, allow participants to reactivate more of the study items at test than in the absence of such a reinstatement task. In consequence, the number of study items in the search set should be enlarged in the 30-min-delay-plus-reinstatement condition, relative to 30-min-delay condition, leading to increased recall rates and increased response latencies. Alternatively, on the basis of trace-decay theory, one may expect that both recall rates and response latencies should not be affected by whether the study context is reinstated before test or not, because, according to this view, prolonged delays induce a permanent loss of the study information.

Method

Participants. Ninety healthy students (19–34 years; M = 24.86 years) at Regensburg University took part in the experiment on a voluntary basis. All participants spoke German as their native language. They were tested individually.

Materials. Materials were identical to Experiment 1.

Design and procedure. The basic procedure of Experiment 2 was similar to Experiment 1, with participants studying and subsequently recalling a list of 18 unrelated items. Experiment 2, however, differed in two aspects from Experiment 1: (a) there was no 10-min delay condition, and (b) we included a 30-min-delay-plus-reinstatement condition. In this reinstatement condition, there was also a 30-min delay between study and test, like in the 30-min-delay condition, but participants engaged in a 1-min context reinstatement task immediately before the test. In this task, participants were asked to write down in brief phrases or words what they were doing immediately before the experiment and what they were thinking and feeling when they entered the laboratory and were seated (Jonker et al., 2013; Sahakyan & Kelley, 2002; Wallner & Bäuml, 2017). The participants' answers at test were recorded and analyzed in exactly the same way as was done in Experiment 1.

Results

Figure 1b shows recall rates (left panel) and mean response latencies (τ; right panel) in the control, 30-min-delay, and 30-min-delay-plus-reinstatement conditions. Figure 2b shows response latency distributions and best-fitting exponential functions for the three conditions.

Recall rates. Regarding recall rates, participants correctly recalled 65.7% of the items in the control condition, 42.8% of the items in the 30-min-delay condition and 51.7% of the items in the 30-min-delay-plus-reinstatement condition. An overall ANOVA of the three conditions (control, 30-min-delay, and 30-min-delay-plus-reinstatement) showed a significant effect of condition, $F(2, 87) = 13.294$, $MSE = 0.030$, $p < .001$, $\eta_p^2 = .234$. Pairwise comparisons revealed significantly lower recall rates in the 30-min-delay condition than the control condition, $t(58) = 5.017$, $p < .001$, $d = 1.295$, reflecting delay-induced forgetting, and significantly higher recall rates in the 30-min-delay-plus-reinstatement condition than the 30-min-delay condition, $t(58) = 2.022$, $p = .048$, $d = 0.522$, reflecting successful mental context reinstatement. Recall was still significantly lower in the 30-min-delay-plus-reinstatement condition than in the control condition, $t(58) = 3.129$, $p = .003$, $d = 0.842$, reflecting that the context reinstatement task did not completely eliminate the detrimental effect of delay.

Response latencies. First response latencies were 1.56 s in the control condition, 1.63 s in the 30-min-delay condition, and 1.77 s in the 30-min-delay-plus-reinstatement condition. An overall ANOVA of the three conditions (control, 30-min-delay, and 30-min-delay-plus-reinstatement) revealed no significant effect of condition, $F(2, 87) = 2.699$, $MSE = 0.127$, $p = .073$, $\eta_p^2 = .058$, suggesting that first response latencies did not vary with condition.

Regarding subsequent response latencies, two-parameter exponentials were fit to the latency functions in the control, 30-min-delay, and 30-min-delay-plus-reinstatement conditions. R^2 values for the best-fitting exponentials were .97, .98, and .97 for the control, 30-min-delay, and 30-min-delay-plus-reinstatement conditions, suggesting that the exponential again accounted for a large portion of the variance in each condition (see Table 1). The mean parameter estimate of asymptotic total (N) revealed values of 57.1% for the control condition, 35.8% for the 30-min-delay condition, and 44.6% for the 30-min-delay-plus-reinstatement condition. N is based on correct and incorrect subsequent responses only, whereas recall rates include first responses as well. Corrected rates, in which only correct and incorrect subsequent responses were included—61.7% in the control condition, 39.8% in the 30-min-delay condition, and 47.8% in the 30-min-delay-plus-reinstatement condition—were similar to the estimated values of N, indicating that recall was close to asymptote in both conditions.

The parameter estimates of mean subsequent response latencies (τ) were 13.9 s for the control condition, 8.9 s for the 30-min-delay condition, and 13.9 s for the 30-min-delay-plus-reinstatement condition. The decrease of 5.0 s from the control to the 30-min-delay condition was reliable, $t(32) = 4.459$, $p < .001$, reflecting the effect of prolonged delay on mean latencies. The increase of 5.0 s from the 30-min-delay to the 30-min-delay-plus-reinstatement condition was also reliable, $t(32) = 4.467$, $p < .001$, suggesting that the context reinstatement task increased response latencies. Parameter τ was identical in the control and 30-min-delay-plus-reinstatement conditions, $t(32) < 1$, suggesting that the context reinstatement task completely eliminated the effect of delay on latencies (Figure 1b, right panel).

Because conventional null hypothesis significance testing cannot argue in favor of the null hypothesis (see Gallistel, 2009; Wagenmakers, 2007), we examined the effect that context reinstatement after delay had on response latencies by estimating the Bayes factor. The Bayes factor reflects the odds in favor of the null hypothesis, and the conditional probability of the null hypothesis given the present response latency estimates for the control and 30-min-delay-plus-reinstatement conditions. We found a Bayes factor of BF = 3.109 in favor of the null hypothesis and a conditional probability of the null hypothesis given the data of $P(H0|D) = .756$. The Bayes factor suggests that the data were 3.1 times more likely to occur under the null hypothesis than under the alternative hypothesis that assumes a difference in response latencies between the control and 30-min-delay-plus-reinstatement conditions. Following Raftery (1995; see also Masson, 2011), this outcome can be interpreted as positive evidence in favor of the null hypothesis that there is no difference in response latencies between the control and 30-min-delay-plus-reinstatement conditions.

Discussion

The results of Experiment 2 show that recall rates and response latencies were decreased when the delay between study and test was increased from 1 to 30 min; thus, replicating the findings of Experiment 1. More important, the context reinstatement task raised recall rates and response latencies after the 30-min delay. Like in Experiment 1, the effects on latencies were mainly driven by effects on subsequent response latencies but not on first response latencies, suggesting effects of delay and context reinstatement on retrieval from the search set rather than retrieval initiation.

The reduced-search-set hypothesis assumes that both recall rates and response latencies can be reduced after prolonged delay because of contextual drift processes that reduce the contextual overlap between study and test. At the same time, the hypothesis also suggests that such overlap can be enhanced again if participants engage in a context reinstatement task immediately before the test. The present results are consistent with this suggestion, showing a decrease in recall rates and response latencies after delay and a rebound of the effects when context was mentally reinstated after delay. Trace-decay theory also assumes that recall rates and response latencies should decrease with prolonged delay, but the theory does not predict any increase in the two measures when context is mentally reinstated. The results of Experiment 2, thus, cannot easily be attributed to trace decay.

While the present results suggest that a reduced search set can play a critical role in delay-induced forgetting, they also provide some indication that reduced item strength contributes to delay-induced forgetting as well. Indeed, if reduced search set size was the sole factor underlying delay-induced forgetting in the present experiment, then the context reinstatement task, which completely eliminated delay-induced-forgetting effects in latencies (see Figure 1b, right panel), should also have eliminated delay-induced-forgetting effects in recall rates. In contrast, the reinstatement task only partly canceled out the detrimental effects of delay on recall rates (see Figure 1b, left panel). This pattern suggests that, while participants were able to include as many items in the search set in the reinstatement condition than in the control condition, some of the items in the search set were still unrecoverable in the 30-min-plus-reinstatement condition, relative to the control condition. This recovery problem indicates that delay not only reduced search set size, but also reduced the memory strength of the studied items in this experiment (Mensink & Raaijmakers, 1988). We address the issue in more detail in the General Discussion.

Experiment 3

Prior work on retroactive and proactive interference has shown that increasing the interference level at test—be it because of prior or subsequent encoding of further nontarget material—reduces recall rates and increases response latencies (Bäuml & Kliegl, 2013; Unsworth et al., 2013; Wixted & Rohrer, 1993). The explanation for the increase in latencies is that, at test, not only target items but also nontarget items are activated and, thus, increase the size of the search set. The present Experiments 1 and 2 on delay-induced forgetting complement this prior work on interference by demonstrating that delay also reduces recall rates. In contrast to retroactive and proactive interference, however, delay reduced response latencies as well. The suggested explanation for the finding is that delay-induced contextual drift can impede the ability to include as many of the target items into the search set as after short delay, which decreases the size of the search set and reduces recall rates. Thus, while both enhanced interference and delay can reduce recall rates, in the one case the reduction is supposed to be because of increased search set size and in the other case to decreased search set size.

The goal of Experiment 3 was to demonstrate the effects of interference and delay-induced contextual drift on recall rates and response latencies within a single experiment. To achieve this goal, three experimental conditions were induced, in each of which participants studied a list of items that they tried to recall after a delay. A control (1-min-delay) condition and a 10-min-delay condition were used to examine delay-induced forgetting, expecting that the increase in delay would create contextual drift and reduce recall rates and response latencies. As a third condition, an interference condition was induced, in which recall, like in the control condition, occurred after a 1-min delay. In contrast to the control condition, however, participants studied a further (nontarget) list of items before the study of the target list. This prior nontarget encoding should enhance the interference level at test and, thus, reduce recall rates but increase response latencies.

We conducted the experiment with both younger and older adults. Older adults are often assumed to be particularly susceptible to interference (Hasher et al., 2002; Lustig et al., 2001). If so, they should show a stronger reduction in recall rates and a stronger increase in response latencies than younger adults when proactive interference is induced. The experiment will show whether older adults' interference susceptibility is accompanied by enhanced contextual drift when the delay between study and test is increased; thus, providing information on whether interference effects and effects of delay-induced contextual drift show similar developmental trends.

Method

Participants. Thirty younger adults (19–27 years; $M = 22.73$ years) and 30 older adults (61–78 years; $M = 67.80$ years) took part in the experiment. Younger adults were recruited from Regensburg University, older adults were recruited from the community. Each participant was tested individually. The two age groups did not differ in the MMSE (Mini Mental State Examination; Folstein, Folstein, & McHugh, 1975; young adults: 29.00; older adults: 28.93), $t(29) < 1$, and the MWT-B (Mehrfachwahl Wortschatz Test [Multiple-choice vocabulary intelligence test]; Lehrl, 2005), a German vocabulary test that measures crystallized intelligence (young adults: 30.40; older adults: 31.39), $t(29) = 1.410$, $p = .164$, $d = 0.368$. The two groups, however, differed in the digit span task (young adults: 16.77; older adults: 13.75), $t(29) = 3.787$, $p < .001$, $d = 1.002$.

Materials. Thirty-six nouns of medium frequency were drawn from the CELEX database using the Wordgen v1.0 software toolbox (Duyck et al., 2004). Twelve items were assigned to each of three item sets. Each item set was used equally often as the target list in the control, interference, and 10-min-delay conditions. In addition, another set of 12 items was drawn from the CELEX database, which always served as the interference list in the interference condition.

Design and procedure. Both younger and older adults took part in three conditions: The control condition, the interference condition, and the 10-min-delay condition. In all three conditions, participants studied a target list of 12 items, and each item was presented visually at a rate of 2.5 s per item. Furthermore, in all three conditions, there was a final free recall test in which participants were given 60 s to orally recall a previously studied target list. Conditions differed with respect to the length of the retention interval and whether or not only the target list was studied: In the control condition, participants studied the target list only and there was a subsequent 1 min retention interval before the test, during which younger participants were asked to count backward in steps of two and older participants were asked to count forward in steps of one. In the interference condition, participants studied an interference list before study of the target list and there was a 1 min retention interval before the test, during which participants engaged in the same counting tasks as in the control condition. In the 10-min-delay condition, participants studied the target list only, and there was a 10 min retention interval before the test, during which all participants additionally engaged in solving Raven's standard progressive matrices (Raven et al., 2000). Between the single experimental conditions, there was a break of 2 min before the next condition started. The participants' answers at test were recorded and analyzed identical to Experiments 1 and 2.

Results

Figure 3 shows recall rates (left panel) and mean response latencies (τ; middle panel) for the target list in the control, interference, and 30-min-delay conditions for the younger and older adults. Figure 2c and 2d show response latency distributions and best-fitting exponential functions for the three conditions, separately for younger and older adults.

Recall rates. Regarding recall rates, a 3 × 2 ANOVA with the factors of CONDITION (control, interference, and 10 min delay) and AGE GROUP (young adults, older adults) revealed main effects of CONDITION, $F(2, 116) = 21.017$, $MSE = .04$, $p < .001$, $\eta_p^2 = .27$, and AGE GROUP, $F(2, 58) = 126.761$, $MSE = .04$, $p < .001$, $\eta_p^2 = .69$, reflecting that overall, younger adults recalled more study items than older adults, and, across age groups, recall was better in the control condition than in the other two conditions. There was also a significant interaction between the two factors, $F(2, 116) = 5.874$, $MSE = .04$, $p = .007$, $\eta_p^2 = .09$, Indeed, while recall rates in the interference condition were significantly decreased relative to the control condition, in both the younger adults (72.8 vs. 83.9%), $t(29) = 2.246$, $p = .033$, $d = 0.417$, and the older adults (25.8 vs. 56.1%), $t(29) = 7.925$, $p < .001$, $d = 1.447$, the decrease was much more pronounced in the older than younger adults (30.3 vs. 11.1%). In the 10-min-delay condition, recall rates were also significantly reduced relative to the control condition for both the younger adults (62.2 vs. 83.9%), $t(29) = 5.066$, $p < .001$, $d = 1.162$, and the older adults (38.3 vs. 56.1%), $t(29) = 3.906$, $p < .001$, $d = 0.713$, but the magnitude of the reduction was similar for the two age groups (21.7% for younger adults vs. 17.6% for older adults).

Response latencies. For younger adults, first response latencies were 1.45 s in the control condition, 1.89 s in the interference condition, and 1.74 s in the 10-min-delay condition; for older adults, first response latencies were 2.03 s in the control condition, 2.27 s in the interference condition, and 1.78 s in the 10-min-delay condition. A 3 × 2 ANOVA with the factors of CONDITION (control, interference, and 10 min delay) and AGE GROUP (young, old) revealed no main effects of CONDITION, $F(2, 116) < 1$, or age group, $F(1, 58) = 2.509$, $MSE = 1.94$, $p = .119$, $\eta_p^2 = .04$, and no interaction between the two factors, $F(2, 116) < 1$.

Regarding subsequent response latencies, for both age groups, two-parameter exponentials were fit to the latency functions in the control, interference, and 10-min-delay conditions. For younger adults, R^2 values for the best-fitting exponential were .99, .95, and .99 for the control, interference, and 10-min-delay conditions; for older adults, R^2 values for the best-fitting exponential were .99, .84, and .95 for the control, interference, and 10-min-delay conditions (see Table 2). These numbers suggest that the exponential accounts for a large portion of the variance in each condition.

For younger adults, the parameter estimate of asymptotic total (N) revealed values of 77.8% for the control condition, 71.1% for the interference condition, and 53.9% for the 10-min-delay condition. Corrected rates, in which only the subsequent responses were included but not the first responses—76.9% in the control condition, and 71.4% in the interference condition, and 56.6% in the 10-min-delay condition—were similar to the estimated values of N, indicating that recall was close to asymptote in each of the three conditions. For older adults, parameter N revealed values of 47.0% for the control condition, 25.6% for the interference condition, and

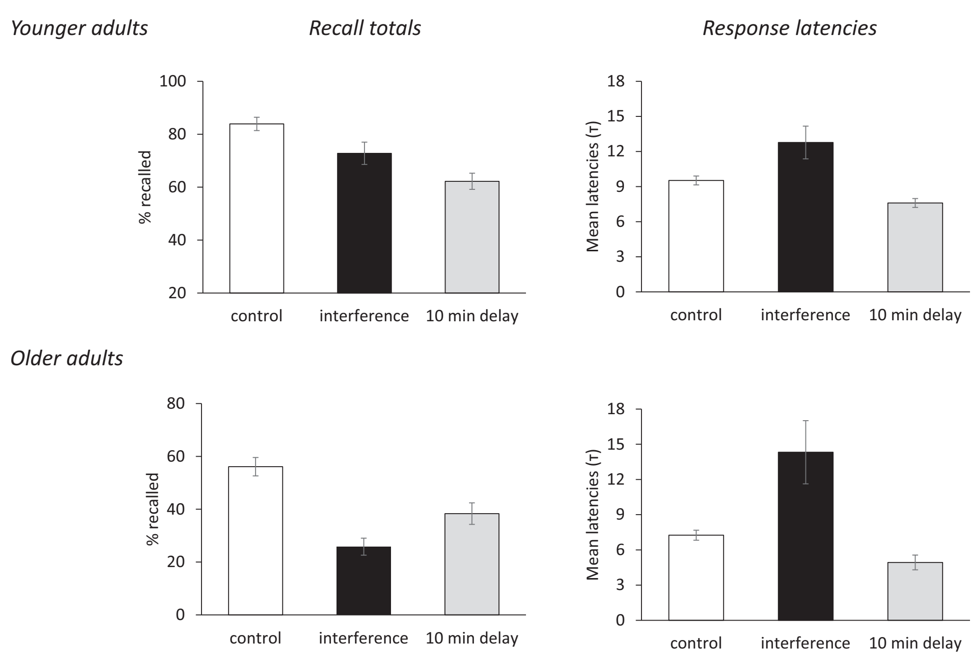

Figure 3. Results of Experiment 3: Percentage recalled and mean response latencies (τ) for the control, interference, and 10-min-delay conditions, separately for younger and older adults. Error bars represent *SE*s.

Table 2
Percentage Recalled, First-Response Latencies, and Subsequent-Response Latencies for Younger and Older Adults in Experiment 3

	% recalled		First-response latency		Subsequent-response latency		
Age group	*M*	*SE*	*M*	*SE*	*M*	*SE*	VAF
Control	83.89	2.53	1.45	.17	9.52	.38	.99
Younger adults							
Interference	72.78	4.21	1.89	.23	12.77	1.40	.95
10-min-delay	62.22	3.81	1.74	.11	7.60	.38	.99
Control	56.11	3.46	2.03	.26	7.25	.43	.99
Older adults							
Interference	25.82	3.23	2.27	.32	14.32	2.69	.84
10-min-delay	38.33	4.07	1.78	.40	4.93	.63	.96

Note. VAF = variance accounted for by the exponential; *M* = arithmetic mean.

27.7% for the 10-min-delay condition. Corrected rates—49.2% in the control condition, 27.5% in the interference condition, and 33.5% in the 10-min-delay condition—were similar to the estimated values of *N*, again indicating that recall was close to asymptote.

The parameter estimates of mean latencies (τ) for younger adults were 9.52, 12.77, and 7.60 s for the control, interference, and 10-min-delay conditions. The increase of 3.25 s from the control condition to the interference condition was significant, $t(20) = 2.240$, $p = .037$, as was the decrease of 1.92 s from the control condition to the 10-min-delay condition, $t(20) = 3.575$, $p = .002$. For older adults, τ estimates for the target list were 7.25, 14.32, and 4.93 s for the control, interference, and 10-min-delay conditions. The increase of 7.07 s from the control condition to the interference condition was significant, $t(20) = 2.595$, $p = .017$, as was the decrease of 2.23 s from the control condition to the 10-min-delay condition, $t(20) = 2.932$, $p = .008$. Like analysis of recall rates, response latency analysis suggests that older adults may be more sensitive to interference effects than younger adults. Indeed, while younger adults showed a reliable increase in response latencies from the control to the interference condition (9.52 vs. 12.77 s), this increase was much more pronounced in older adults (7.25 vs. 14.32 s). In contrast, older adults did not appear to be more susceptible to the detrimental effects of prolonged delay than younger adults, as both age groups were roughly 2.0 s slower in the 10-min-delay condition than the control condition.

Discussion

The results replicate the findings of Experiments 1 and 2 by showing a positive relationship between recall rates and response latencies after prolonged delay, that is, both reduced recall rates and reduced response latencies in the 10-min-delay condition, relative to the control condition. The results further replicate prior work by demonstrating a negative relationship between recall rates and response latencies when interference is induced at test. That is, recall rates were reduced but response latencies were increased in the interference condition, relative to the control condition (Bäuml & Kliegl, 2013; Wixted & Rohrer, 1993). Thus, Experiment 3 provides a first direct demonstration that different types of processes can underlie interference-induced forgetting and delay-induced forgetting: whereas interference-induced forgetting is primarily mediated by the coactivation of nontarget items; thus, resulting in an increased search set at test, delay-induced forgetting can be because of participants' inability to include study items in the search set, resulting in a decreased search set at test. This holds while the two forms of forgetting have similar effects on recall rates.

As expected, older adults showed a higher susceptibility to the effects of interference than younger adults, with a more pronounced reduction in recall rates and a more pronounced increase in response latencies. The latency results suggest that older adults' higher susceptibility to interference originated from an increased tendency to coactivate nontarget items, relative to younger adults. In contrast, older adults showed no increased susceptibility to the effects of delay. Rather, the reduction in recall rates and response latencies was similar between the younger and older adult groups, indicating that the two age groups showed comparable effects of contextual drift. This pattern of results suggests different developmental trends for interference-induced versus delay-induced forgetting with older age.

General Discussion

Effects of Contextual Drift in Delay-Induced Forgetting

The results of all three experiments demonstrate that prolonged delay filled with neutral distractor tasks can reduce both recall rates and response latencies. This pattern of results is inconsistent with the interference view of delay-induced forgetting. According to this view, participants are exposed to intervening material during the delay and, at test, use retrieval cues that not only lead to activation of the studied items but to coactivation of the intervening material as well. The induced increase in search set size at test then results in a decrease in recall rates as well as an increase in response latencies. While the present findings show the expected decrease in recall rates, they show a decrease rather than an increase in response latencies, which challenges the interference view.

Rather, the present results are consistent with the contextual drift view of delay-induced forgetting. According to this view, temporal context changes with delay and reduces the contextual overlap between study and test (Estes, 1955; Tulving, 1972). Such delay-induced contextual drift has often been assumed to mainly affect the studied items' memory strength, making retrieval of the items more difficult (Mensink & Raaijmakers, 1988). However, contextual drift may also influence the size of the search set at test. Indeed, the reduced contextual overlap between study and test may lead participants to use retrieval cues at test that specify a smaller number of study items than after short delay; thus, reducing search set size at test (Unsworth et al., 2011). While both hypotheses agree in their prediction of reduced recall rates with delay, the reduced-search-set hypothesis predicts a decrease in response latencies with delay, whereas the reduced-strength hypothesis predicts unaffected response latencies. The results of all three experiments showed a reduction in response latencies with delay, suggesting that delay-induced contextual drift reduced search set size at test.

Several studies in the literature have shown that a reduced contextual overlap between study and test can be (partly) overcome by mental context reinstatement before test (Jonker et al., 2013; Sahakyan & Kelley, 2002; Wallner & Bäuml, 2017). On the basis of these findings, a natural prediction of the reduced-search-set hypothesis is that the reduction in search set size after delay can be (partly) eliminated when mental context is reinstated before test. Experiment 2 examined this prediction, comparing recall rates and response latencies after delay in the presence versus absence of a context reinstatement task. Results were consistent with the prediction, showing an increase in both recall rates and response latencies in the presence versus absence of the context reinstatement. Moreover, the context reinstatement eliminated the decrease in search set size after delay nearly completely, indicating that contextual drift can decrease search set size at test but context reinstatement before test again eliminates the effect.

The reduced-strength hypothesis and the reduced-search-set hypothesis are mutually nonexclusive. Accordingly, in principle, contextual drift could reduce search set size at test as well as reduce item strength. While the results of all three experiments are indicative for a reduction in search set size at test, the results of Experiment 2 suggest that contextual drift can reduce item strength as well. The results of this experiment showed that, although after mental context reinstatement latencies were again comparable to the (short delay) control condition, recall rates were still lower than in the control condition, suggesting that the items were reduced in strength. These findings are in line with the view that delay-induced contextual drift can both reduce search set size at test and weaken the strength of the studied items. Thus, contextual drift processes can come with two separable effects on studied items.

Possible Alternative Interpretations of the Present Results

Arguably, other factors besides contextual drift may have mediated the present results. As a first alternative interpretation of the present results, the findings, for instance, may be attributed to interference-based unlearning. Although there is broad consensus in the memory literature since at least the end of the 1980s that retrieval competition is the critical factor in interference (e.g., Mensink & Raaijmakers, 1988), following Melton and Irwin's (1940) classic two-factor theory of interference, one may suggest that unlearning has mediated the present results. Unlearning is defined as a reduction or even elimination of associative strength between a cue and its associated target item(s) caused by the subsequent encoding of further items. Such unlearning may have reduced or even eliminated the association between some of the target items and the context cue after prolonged delay; thus, reducing search set size and speeding the recall process. There is generally little empirical support in the literature for unlearning (e.g., Mensink & Raaijmakers, 1988; Tulving & Madigan, 1970), however, and the findings of Experiment 2 also challenge this account. Indeed, if unlearning had mediated the reduction in response latencies with delay as it was observed in the present experiments, then the reduction should have been permanent and not be eliminated by the mental context reinstatement used in Experiment 2. The results of Experiment 2, thus, appear inconsistent with an unlearning interpretation of the present results.

As a second alternative interpretation of the present results, the reduction in response latencies with delay may be attributed to self-termination processes. Although a look at the latency functions depicted in Figure 2 suggests that participants continued searching throughout the whole recall period, some participants may have self-terminated recall before then. Conceivably, after prolonged retention interval, some participants may have assumed that they would not be able to recall a large number of items and terminated the search prematurely, which could explain the observed reduction in mean latency with delay. If so, it seems unlikely that participants already ended their memory search within the first half of the recall period and, therefore, restricting latency analysis to that early time interval should mostly eliminate potential effects of self-termination. Therefore, we estimated response latencies once again for all three experiments, but included only the latency data from the first half of the recall period. Mean latency estimates for the first half of the recall period mimicked those reported above for the whole recall period,[1] indicating that self-termination was not the critical factor for the reported difference in latencies between short and long delay.

Finally, the latency measures reported above were based on an analysis of group data (e.g., Bäuml et al., 2005), which raises the question of whether they were representative of the individual participant data. To address the concern, we repeated the latency analysis for Experiments 1 and 2, this time fitting the two-parameter exponential to the latency functions of each individual participant. As it turned out, the pattern of results replicated the results reported above, indicating that the group data in the two

[1] Regarding Experiment 1, the additional analysis led to mean latency (τ) estimates of 12.93 s (SE = 0.97) for the control condition, 10.67 s (SE = 0.68) for the 10-min-delay condition, and 8.83 s (SE = 0.67) for the 30-min-delay condition, again demonstrating that latencies were reduced with prolonged delay. Regarding Experiment 2, the additional analysis led to τ estimates of 13.44 s (SE = 1.13) for the control condition, 8.86 s (SE = 0.76) for the 30-min-delay condition, and 13.57 s (SE = 1.25) for the 30-min-delay-plus-reinstatement condition, again demonstrating reduced latencies with prolonged delay and increased latencies following context reinstatement. Similarly, the estimates for Experiment 3 mimicked those reported above.

experiments were fairly representative of the individual data.[2] This holds while the present experiments were clearly not designed for response latency analysis of individual participant data, as is reflected by the fact that the number of items recalled from each single participant was generally relatively low, which impedes estimation of the exponential's parameters. Future work may address the issue of individual response latency analysis more thoroughly, for instance, by increasing the number of items used in the single study lists or increasing the number of study-test trials per participant (see Kliegl et al., 2015; Wixted & Rohrer, 1993).

Relation to Prior Work

The present study examined contextual drift effects as they are induced by prolonged delay. Unsworth et al. (2012) examined contextual effects when delay was short and constant, and context between study and test was changed by either having participants tested in a different room as the material was learned, or by having them engage in an imagination task before test. Both changes in context resulted in reduced recall rates but had no effect on response latencies. While this finding agrees with the one present result that contextual drift can reduce item strength (Experiment 2), it differs from the other present result that context drift can also decrease search set size (Experiments 1–3). One explanation for the difference in findings could be that delay-induced contextual drift induces stronger contextual effects than the context changes induced in Unsworth et al.'s work, and a reduction in search set size arises only after such stronger contextual change. Alternatively, the difference in results may also have to do with differences in how response latencies were analyzed. In the present study, mean latency was estimated by fitting a two-parameter exponential to the data, whereas Unsworth et al. (2012) estimated mean latency by direct averaging of the single response latencies. The two estimates do not necessarily lead to equivalent results. For instance, if recall is not asymptotic at the end of the recall period, then calculating mean latency by averaging the single response latencies can lead to biased measures of mean latency (Rohrer, 1996). Future work may address the issue, comparing the effects of delay-induced context drift and, for instance, imagination-induced context change directly, to see whether they induce equivalent or partly different effects on search processes.

While the present results indicate a major role of contextual drift in delay-induced forgetting, they do not rule out that interference can contribute to the forgetting as well. Indeed, the present results are well compatible with the view that both context drift and interference play a role in delay-induced forgetting but that, with neutral retention intervals in which encoding of interfering information should be sparse, context drift plays a much stronger role than interference, which is why latencies decreased, rather than increased, with delay in the present study. On the basis of this more general view, the prediction may arise that the present findings will not generalize to all types of delay. Indeed, to the extent that delay is filled with the additional learning of interfering nontarget material, the relative contribution of interference to delay-induced forgetting should increase and that of contextual drift decrease. Moreover, if the relative contribution of interference overweighted that of contextual drift, the decrease in latencies as observed in the present experiments should not only be reduced but even be reversed.

While the suggested transition from reduced to increased latencies has not yet been demonstrated in the delay literature, there is one study which supports this more general view. Unsworth et al. (2011) found that after encoding of some target paired associates, and the encoding of further nontarget associates during subsequent delay, response latencies increased with delay. Although delay in this experiment may also have induced a reduction in search set size for the target items, as was found in the present study, because of the encoding of the interfering nontarget items, it may have led to the additional coactivation of nontarget items at test. If this effect of coactivation of nontarget items increased search set size more than the reduced activation of target items decreased search set size, then, as a net result, size of mental search set should have increased at test, leading to the increase in latencies that Unsworth et al. reported in their study. Future work may address the issue more directly by examining in more detail how the encoding of interfering material during delay can change the effect of delay from reduced latencies (reduced search set) in the absence of interference to increased latencies (increased search set) in its presence.

The present experiments examined how search processes for a studied target list are influenced by delay when the retention interval between study and test is neutral and does not include the encoding of interfering information. Wixted and Rohrer (1993, Experiment 2) examined a related issue but, in contrast to the present study, asked participants to study further nontarget lists *before* study of the target list; thus, inducing proactive interference. No conditions were included in the experiment, in which the study of the prior nontarget lists was absent. Results found target list recall to decline from a short delay of 3 s to a prolonged (neutral) delay of 27 s, but found response latencies to increase with the delay. Wixted and Rohrer suggested that the discriminability between the target material and the previously learned nontarget material was impaired with prolonged delay, thus, leading to a more pronounced coactivation of nontarget items after delay and, thus, an increase in search set size. Although at first glance these findings may appear inconsistent with the present results, they do not disagree with the present view that, after delay, a reduced set of the target items is activated at test. Indeed, also in the presence of proactive interference, the number of activated target items may decrease with delay. However, if, at the same time, delay leads to an increase in number of activated nontarget items—for instance, because of a delay-induced impairment in list discrimination—this increase may outweight the decrease in activated target items and, thus, increase search set size at test. Future work may examine the issue in more depth.

[2] Regarding Experiment 1, τ estimates were 14.97 s (SE = 2.17) for the control condition, 10.16 s (SE = 1.06) for the 10-min-delay condition, and 7.78 s (SE = 1.05) for the 30-min-delay condition, again demonstrating that latencies were shortened with prolonged delay. Regarding Experiment 2, τ estimates were 13.71 s (SE = 1.44) for the control condition, 10.24 s (SE = 1.15) for the 30-min-delay condition, and 14.06 s (SE = 1.69) for the 30-min-delay-plus-reinstatement condition, again demonstrating shortened latencies with prolonged delay and increased latencies after context reinstatement. Note that we excluded participants with highly unreliable mean latency estimates from the sample, that is, participants whose R^2 values for the best-fitting exponential were below 0.2. We did not analyze individual latency functions in Experiment 3, because in this experiment number of items recalled from each single participant was even smaller than in Experiments 1 and 2.

Contextual Drift and Interference Effects in Older Adults

Experiment 3 examined proactive interference effects in both younger and older adults, comparing recall levels and response latencies between an interference condition, in which there was prior encoding of other material, and a control condition, in which there was no such prior encoding. As expected, the results of the experiment showed proactive interference effects in both younger and older adults, but the results also revealed a much higher proactive interference effect in older adults, which supports the hypothesis that older adults suffer from an enhanced susceptibility to interference (Hasher et al., 2002; Lustig et al., 2001). In fact, proactive interference reduced older adults' recall much more than of younger adults, and increased older adults' latencies much more than of younger adults. The age effect on latencies indicates that the prior encoding of the nontarget material increased mental search set size to a much higher degree in older than younger adults, suggesting that more nontarget items were coactivated at test in the older adults.

In contrast, the results of Experiment 3 show that younger and older adults did not much differ in delay-induced forgetting, with the two age groups showing roughly comparable reductions in both recall rates and response latencies. This finding indicates that delay-induced contextual drift reduced search set size in both younger and older adults, and reduced search set size to a similar degree. Whether the two age groups also showed comparable reductions in item strength with delay is less clear, although the finding that the two age groups showed similar decrease in latencies *and* similar decrease in recall rates, is at least consistent with such a view. Future work is required to address this issue more directly. In the absence of such work, the present findings suggest that contextual drift effects and interference effects show different developmental trends in older age, with mainly interference effects and much less contextual drift effects increasing with age.[3]

Conclusions

In this series of experiments we showed that contextual drift processes play a critical role in delay-induced forgetting. When the retention interval between study and test is filled with neutral distractor tasks, contextual drift can influence recall by reducing studied items' memory strength and by reducing mental search set size at test. In consequence, both recall rates and recalled items' response latencies decrease with delay. Mental context reinstatement before test can eliminate the effect of delay on mental search set, so that retrieval speed is no longer influenced by delay. As a whole, the findings suggest that, with neutral delays, delay-induced forgetting is primarily mediated by contextual drift and much less, if at all, by enhanced interference.

[3] Experiment 3 showed that response latencies were considerably shorter in older than younger adults, both after short and long delay. This finding may indicate that, even after short delay, older adults can have problems at generating adequate retrieval cues at test, which then leads to fewer items being included in the mental search set than in younger adults. Alternatively, older adults may simply not have encoded as many items as younger adults, for instance, because during study, they blinked or looked away from the index cards, a behavior that would also lead to reductions in search set size at test and reduced response latencies.

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