(Only) Time Can Tell: Age Differences in False Memory Are Magnified at Longer Delays

Yana Fandakova, Markus Werkle-Bergner, and Myriam C. Sander
Max Planck Institute for Human Development, Berlin, Germany

Older adults often report memories of past events that are partly false. To date, age differences in memory errors have primarily been examined after a delay of minutes to hours. However, in real-life situations we rely on memories formed days to weeks in the past. We examined associative memory for unrelated scene-word pairs in younger and older adults after 24 hr and 8 days. Age differences in memory were magnified after 8 days due to a disproportionate increase in false alarms to rearranged pairs in older adults. In both age groups, the effects of delay were modulated by memory fidelity and whether or not participants had experienced similar events, which potentially caused interference. Older adults were particularly vulnerable to associative memory errors having experienced similar events, even when the initial memory was of high fidelity. We suggest that the fidelity of memory representations in concert with monitoring processes to resolve interference determine how the passage of time affects the propensity to falsely remember details of the past.

Keywords: aging, decay, interference, fidelity, binding

With aging, the ability to remember details about the past, such as where, when, or how specific events happened, declines (Spencer & Raz, 1995). Older adults show worse memory for the binding among different features of an event and are also more likely to remember associative information that is partly false (Devitt & Schacter, 2016; Dodson, 2017; Fandakova, Shing, & Lindenberger, 2013; Shing, Werkle-Bergner, Li, & Lindenberger, 2008, 2009). Accordingly, memory complaints are among the most prevalent cognitive complaints of older adults (Fritsch, McClendon, Wallendal, Hyde, & Larsen, 2014; Hertzog, Hülür, Gerstorf, & Pearman, 2018). Unsurprisingly, falsely remembering the past, for example falsely recalling medical instructions, can negatively affect future decisions and actions, and could endanger independent living and quality of life in later adulthood (Farias, Mungas, & Jagust, 2005).

In the laboratory, associative memory is typically examined by asking participants to memorize pairs of stimuli that are later tested in an intact or a rearranged form (i.e., by combining items that were originally studied as parts of different pairs). To date, age differences in associative memory have been examined primarily at relatively short delays within 24 hr of the initial event. However, real-life decisions typically rely on memories acquired across longer periods. This leads to the question, does a longer interval between memory formation and retrieval differentially influence older adults' propensity for memory errors? Here, we tested the hypothesis that older adults show an enhanced susceptibility to memory errors after longer delays, resulting in the magnification of age differences in associative memory over time.

Two main sources are thought to contribute to age differences in associative memory (e.g., Shing et al., 2010): Differences in the fidelity of underlying memory representations (Benjamin, 2010; Fandakova et al., 2018; Li, Naveh-Benjamin, & Lindenberger, 2005) and less efficient cognitive control processes to monitor memory retrieval (Dodson, 2017; Giovanello & Schacter, 2012; Gutchess et al., 2007; Mitchell & Johnson, 2009). In associative memory, the fidelity of contents of memory critically depends on the binding of different features of an episode into a coherent representation (Eichenbaum & Cohen, 2001). This ability declines with aging, resulting in pronounced associative memory deficits (Old & Naveh-Benjamin, 2008). Cognitive control processes that serve to monitor retrieval become particularly important when the fidelity of the underlying memory representations is low, for example, when mnemonic evidence is scarce (Rugg, 2004) or when memories are less distinct and very similar to each other (Dulas & Duarte, 2016).

But how does the passage of time between encoding and retrieval influence memory fidelity? One influential definition of forgetting regards it as loss or decay of information over time (for review see Roediger, Weinstein, & Agarwal, 2010). Decay is thought to manifest as a loss of detail and coherence of memory traces upon longer delays (Sadeh, Ozubko, Winocur, & Moscovitch, 2014; Sekeres et al., 2016; Winocur & Moscovitch, 2011). Therefore, we expected that with the loss of information, associa-

tive memory fidelity would decrease, resulting in a higher likelihood for memory errors at longer versus shorter delays.

Changes in memory over time may also critically depend on the level of fidelity of the memory representation created during initial learning. For example, decay may decrease the probability of correctly recalling an association formed with a relatively high fidelity during initial learning. At the same time, an initially lower-fidelity association may become completely inaccessible over time (Habib & Nyberg, 2008; Yang et al., 2016). This idea would be consistent with findings that loss of information over time is not uniform across types of information such that peripheral elements of an episode are more susceptible to forgetting over time than elements that are central to the event (Sekeres et al., 2016). Similarly, the accessibility of low-fidelity associations may suffer more from decay than the accessibility of high-fidelity associations.

Evidence for age differences in forgetting over time is mixed (Elliott, Isaac, & Muhlert, 2014). With respect to associative memory, one study found that cued recall performance for word–word pairs showed a greater decrease in older adults than in younger adults between 30 min and 7 days following learning (Mary, Schreiner, & Peigneux, 2013). However, associative recognition was only tested 7 days after learning, and showed more associative memory errors in older adults, indicating that age differences in memory errors may be particularly sensitive to decay. To date, it is an open question how younger and older adults actually differ in the rate with which associative representations are forgotten over time and what candidate mechanisms underlie those changes. In the present study, we set out to examine how shorter versus longer delays between learning and retrieval affect the likelihood of committing associative memory errors in younger and older adults, and whether these effects of delay depend on the fidelity of the initial memory representation. To investigate the modulatory effects of initial memory fidelity, we used a paradigm that allowed us to compare memory traces of varying fidelity within the same participants at shorter and longer delays.

In reality, of course, we rarely retrieve past events only once after a prolonged period of time. Rather, in most everyday situations we experience similar events that share cognitive representations with the original event, such as parking one's car in the same street every evening, but in a slightly different location. Such daily routines create strong representational overlap and render it difficult to recall the car's actual location when leaving the house for work in the morning (Yassa & Reagh, 2013). From an ecological point of view, the likelihood that we experience the same or similar episodes and thereby also retrieve an earlier episode, increases over time (Hardt, Nader, & Nadel, 2013). Thus, experiencing similar events induces moments of instability when new information may be partially incorporated in the original memory trace, paving the way for memory errors. Thus, to arrive at a better understanding of whether and how the likelihood of memory errors changes over longer delays, we need to take the effects of representational overlap into account.

One way to study overlapping representations, or interference, over longer delays, is by presenting participants with additional materials that are similar to the target events (Roediger et al., 2010; Sadeh et al., 2014). This approach is consistent with studies of false memory using the misinformation paradigm (cf. Loftus, 2005) in which presenting additional related, but misleading in-

formation, produces reliable memory errors when tested immediately as well as after longer delays (Zaragoza & Mitchell, 1996). In line with these results, we expected that having processed similar materials would result in overlapping representations and more memory errors, especially for associations with initially low fidelity, which may be more susceptible to interference (Sadeh, Ozubko, Winocur, & Moscovitch, 2016).

Resolving interference as a result of encountering similar materials requires greater engagement of monitoring processes to avoid errors (e.g., Fandakova, Lindenberger, & Shing, 2014). We expected this to be particularly challenging for older adults, resulting in more associative memory errors (Fandakova et al., 2014). Accordingly, one study examined age differences in recognition memory for complex visual scenes immediately after learning and four weeks later by increasing demand on monitoring processes (Park, Puglisi, & Smith, 1986). In particular, the delayed test required participants to discriminate between initially studied scenes and distractor scenes that were also included in the immediate test. Under these conditions of increased demands for monitoring source information, the difference in false alarm rates over time was greater for older than for younger adults. These initial results suggest that memory errors may increase at longer delays. Thus, we expected that greater representational overlap at longer delays accompanied by monitoring deficits should have an exacerbating effect on the propensity to commit memory errors, creating a double-jeopardy situation for older adults.

Taken together, older adults commit more memory errors than younger adults do at delays up to 24 hr (Devitt & Schacter, 2016). To date, the mechanisms by which extended delays affect age differences in associative memory errors are unknown. Such delays are associated with loss of mnemonic fidelity through (a) loss of information, or decay; and (b) increasing representational overlap via experience with similar events. While both of these mechanisms may affect younger and older adults differentially, we expected older adults to be particularly vulnerable to false associative memories for initially low-fidelity representations that become less detailed over time and therefore put high demands on monitoring processes.

To examine these questions, we asked younger and older adults to learn a large number of unrelated scene-word pairs. Following, we utilized an associative memory paradigm to test their memory for these pairs at shorter and longer delays. Specifically, on Day 1 participants learned the unrelated scene–word pairs via repeated cued-recall cycles with feedback to induce memory representations of varying fidelity for each participant (see Figure 1A–B). Based on a final cued-recall test (in which no feedback was provided; Figure 1C), we sorted pairs depending on whether participants managed to successfully remember the word when cued with the scene or not. Thus, in the present design, we defined high-fidelity pairs as those for which scene–word binding was successful, as reflected in the ability to recall the word when cued with the scene in the final cued-recall test on Day 1. Low-fidelity pairs were defined as a failure to bind the scene with the corresponding word, as reflected in a failure to correctly recall the word when cued with the scene binding in the final cued-recall test on Day 1.

To examine memory retrieval at a shorter delay, participants returned 1 day after learning (i.e., Day 2) for an associative memory test in which they were presented with intact and rearranged pairs of low-fidelity and high-fidelity stimuli (see Method
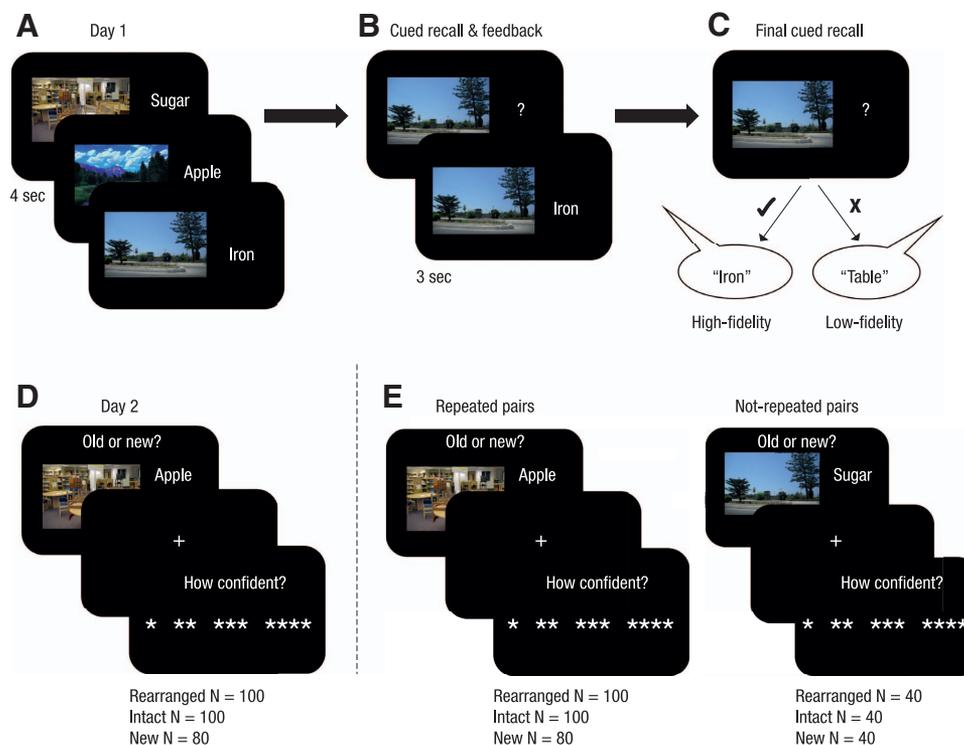
Figure 1. Experimental paradigm. (A–C) Younger and older adults memorized random scene–word pairs using an imagery strategy and repeated cued recall cycles (Day 1). (D) Day 2 (short delay): 24 hr after learning, participants completed an associative recognition task for a subset of the scene–word pairs from Day 1. (E) Day 8 (long delay): 8 days after learning, participants returned for another associative recognition test that included pairs they had seen on Day 2 (repeated pairs) as well as pairs that were studied on Day 1, but not presented on Day 2 (not-repeated pairs). In each associative recognition task, intact, rearranged, and new pairs were presented intermixed (only an example of a rearranged pair is displayed). Following each old/new decision, participants were asked about their confidence in their answer on a four-point scale marked by asterisks presented on the screen. See the online article for the color version of this figure.

section for details). We focused on false alarms to rearranged pairs (i.e., rearranged pairs that were falsely endorsed as studied on Day 1) as a measure of the propensity for memory errors for low- and high-fidelity pairs at a shorter delay, and age differences therein. Based on previous results with the same procedure (Fandakova et al., 2018), we expected that older adults will be more likely than younger adults to commit memory errors on Day 2, and that these age differences will not be eliminated for high-fidelity pairs.

To examine associative memory at a longer delay, participants returned for a second associative memory test 7 days later (i.e., Day 8). Here, they were again presented with intact and rearranged pairs of low- and high-fidelity stimuli (as defined based on the respective recall success in the learning procedure on Day1). Critically, this test included all pairs tested at the shorter delay on Day 2 along with pairs that were not tested on Day 2. Comparing false alarms for rearranged pairs that were only tested on Day 8 against the baseline of false alarm rates on Day 2 allowed us to test how loss of information affects memory errors in younger and older adults at the longer delay. We expected that the effects of decay depend on the initial memory fidelity of a pair such that memory errors were more likely to increase for high-fidelity than for low-fidelity pairs for which more details are lost over time. If

aging is associated with an accelerated loss of details, we expected a greater increase in false alarms to high-fidelity pairs on Day 8 compared with Day 2 in older adults. Finally, comparing age differences on Day 8 for false alarms to rearranged pairs that had also been encountered on Day 2 allows us to examine the effects of representational overlap. In line with evidence from the misinformation and interference studies (e.g., Zaragoza & Mitchell, 1996), we expected that representational overlap would result in increased false alarms on Day 8 in both age groups. In addition, we expected that monitoring deficits in older adults will result in a greater increase in false alarm rates relative to Day 2 in older than in younger adults, especially for low-fidelity pairs.

Method

Participants

Participants in this study were 31 younger adults (20–25 years) and 39 older adults (68–73 years). Sample size was chosen in line with our previous study (Fandakova et al., 2018) using a similar paradigm, demonstrating how memory fidelity influences age differences in false memory after short delays. In order to ensure that

at least 20 scene–word pairs in each of the high- and low-fidelity conditions were available for the recognition test on Day 8, older participants had to achieve between 20% and 80% accuracy and younger participants between 13% and 87% accuracy on Day 1. Two younger adults and six older adults did not perform within these ranges and were excluded from further analyses. Five additional older adults were excluded for technical reasons, and two older adults dropped out before completing all assessments. Finally, two younger adults demonstrated a low overall memory performance (i.e., hits–false alarms; Snodgrass & Corwin, 1988) on both Day 2 and Day 8 (defined as $p < .001$ relative to their age group) and were removed from further analyses. The final sample consisted of 27 younger adults (14 female, $M = 23.34$, $SD = 1.38$ years) and 26 older adults (14 female, $M = 72.02$, $SD = 1.67$ years). Participants were native German speakers, had normal or corrected-to-normal vision, no history of psychiatric or neurological disease, and did not take psychiatric medication. Older adults were screened for cognitive impairment with the Mini-Mental State Exam (Folstein, Folstein, & McHugh, 1975) and all scored above 26 points ($M = 29.08$, $SD = 0.80$). The study was approved by the ethics committee of the Max Planck Institute for Human Development, Berlin, Germany.

Materials and Procedure

We used an associative recognition paradigm to test younger and older adults' memory for scene–word pairs after 24 hr and after 8 days of the initial associative learning (see Figure 1).

Day 1. Participants were first instructed to memorize random scene–word pairs using an imagery strategy. The scenes consisted of indoor and outdoor scenes and were randomly paired with concrete two-syllable nouns (for more details, see Fandakova et al., 2018). Participants were encouraged to generate integrated vivid images of the pairs and practiced using the imagery strategy prior to the main experiment. Scene–word pairs were presented for 4 s and participants were instructed to remember the pair and to indicate how well they could form an integrated image of the scene–word pair on a 4-point scale (Figure 1A; the ratings were not analyzed for the present article). Participants then performed cued-recall blocks (one for younger adults, two for older adults). Here, scenes served as cues to verbally recall the associated word (Figure 1B). Recall time was not constrained. Independent of recall accuracy, the correct scene–word pair was presented again for 3 s, fostering further learning of the pair. Following this, participants completed a final cued-recall phase without feedback (Figure 1C). Here, scenes served as cues to recall the associated word but no feedback was provided.

As in previous studies with this paradigm (Fandakova et al., 2018; Muehlroth et al., 2019; Sommer et al., 2019), task difficulty was adjusted between age groups to achieve recall success close to 50% in each age groups. Younger adults studied 440 pairs and older adults studied 280 pairs. In addition, younger adults completed one cued-recall block with feedback, whereas older adults completed two.

We used performance on the final cued-recall phase on Day 1 to form intact and rearranged pairs for associative recognition tests on Day 2 and Day 8. Scene–word pairs presented on Day 1 were sorted into two categories based on each individual's performance in the final cued-recall phase on Day 1: (a) high-fidelity pairs were defined as pairs for which participants correctly recalled the corresponding word when presented with the scene; and (b) low-fidelity pairs were defined as pairs for which participants did not successfully recall the word when presented with the scene. For older adults, all 280 studied pairs were assigned to one of these categories. Next, 40 high-fidelity and 40 low-fidelity pairs were set aside to be used on Day 8 as intact and rearranged pairs (20 per condition). The remaining 200 pairs were divided equally between the intact and rearranged pair conditions on Day 2. Because younger adults studied more than the 280 pairs used for recognition tests across shorter and longer delays, we randomly chose 100 high-fidelity and 100 low-fidelity pairs for Day 2 as well as 40 high-fidelity and 40 low-fidelity pairs for Day 8 from the larger set of studied pairs. If younger adults' learning success did not allow this ($N = 10$ participants), we split the available high- or low-fidelity pairs in half between intact and rearranged pairs for Day 2.

The experimental manipulation on Day 1 was successful in creating variability in associative binding success in both younger adults, $M = 52.65\%$, $SD = 18.99\%$, and older adults, $M = 43.67\%$, $SD = 16.29\%$, thereby allowing us to create sets of intact and rearranged pairs that included both high- and low-fidelity scene–word pairs uniquely determined for each participant. Final recall on Day 1 did not differ significantly between the age groups, $t(50) = 1.83$, $p = .07$, $d = 0.51$.

Day 2. Approximately 24 hr after learning on Day 1, participants completed an associative recognition task with scene–word pairs from Day 1 (Figure 1D). Participants were presented with 100 intact scene–word pairs (i.e., scene and word presented together as a pair on Day 1; consisting of parts of high-fidelity and low-fidelity pairs), 100 rearranged pairs (i.e., scene and word presented as parts of different pairs on Day 1; consisting of either high- or low-fidelity pairs), and 80 new pairs (i.e., scenes and words had not been seen before).

Scene–word pairs were presented for 3.5 s, and participants indicated whether the pair was old (i.e., an intact pair) or new (i.e., a rearranged or new pair). Participants then rated their confidence in their decision on a 4-point scale (unlimited response time). As in our previous work with this paradigm (Fandakova et al., 2018), jittered fixation cross periods (500–6,500 ms) were presented after each memory and confidence decision. The task was completed in five blocks of 56 trials (20 intact, 20 rearranged, 16 new pairs).

Day 8. Approximately 7 days after the associative recognition task on Day 2, participants returned for another associative recognition test (Figure 1E). Here, they were presented with the 100 intact scene–word pairs they had seen on Day 2 as well as with 40 intact pairs (20 high- and 20 low-fidelity) that were studied on Day 1, but were not presented on Day 2. In addition, participants viewed the 100 rearranged pairs presented on Day 2 along with 40 rearranged pairs (20 high- and 20 low-fidelity) they had not seen before, but came from scenes and words they had learned on Day 1.

Finally, 40 new pairs were presented along with the 80 new pairs from Day 2. Identical to Day 2, on Day 8 scene–word pairs were presented for 3.5 s, followed by a confidence rating on a 4-point scale and a jittered fixation cross (500–6,500 ms). Intact, rearranged, and new pairs presented on both Day 2 and Day 8 as well as those only presented on Day 8 were intermixed and presented in a different order than on Day 2. Participants were instructed to respond by pressing "old" *only* to pairs that were exactly the same as on Day 1, irrespective of whether they had

seen them on Day 2 as well. A practice block preceded the main task to ensure that participants understood the instructions and could successfully perform the task. The task was completed in five blocks of 80 recognition trials each (28 intact, 28 rearranged, 16 new pairs from Day 2, and eight completely new pairs). Comparing false alarms to rearranged pairs on Day 2 (i.e., at the shorter delay), to false alarms to rearranged pairs tested only once on Day 8 (i.e., at the longer delay), or *not-repeated pairs*, allowed us to evaluate the effects of decay. Comparing false alarms to rearranged pairs on Day 2 to false alarms to the same rearranged pairs when they were again tested on Day 8, or *repeated pairs*, allowed us to evaluate the effects of representational overlap, or interference. The alpha level for all statistical analyses was set to $\alpha = .05$ with a false discovery rate correction for multiple comparisons of post hoc tests (indicated by p_{corr}).

Results

Age Differences in Recognition Memory at Shorter and Longer Delays

We first sought to determine if recognition memory differentially decreased between Day 2 and Day 8 in younger and older adults.

First, we computed the discrimination index of recognition memory based on the two high-threshold model (Snodgrass & Corwin, 1988). The discrimination index was computed as $Pr =$ Hit Rate$_{target\ pairs}$ − False Alarm Rate$_{rearranged\ pairs}$. A mixed analysis of variance (ANOVA) was conducted to examine the effects of delay (Day 2 vs. Day 8) and age group (younger vs. older adults) on the discrimination index. There was a significant main effect of delay, $F(1, 51) = 126.21$, $p < .001$, $\eta_p^2 = .71$, indicating that memory performance decreased with longer delays in both groups (see Figure 2). The main effect of age group was also significant, $F(1, 51) = 22.91$, $p < .001$, $\eta_p^2 = .31$, with overall lower memory in older adults than in younger adults. Also, the interaction effect was significant, $F(1, 51) = 21.61$, $p < .001$, $\eta_p^2 = .30$, indicating that longer delays had a greater negative effect on older adults' performance (see Figure 2).

Age Differences in Response Bias at Shorter and Longer Delays

One concern is that magnification of age differences in memory at longer delays may, at least partially, be driven by changes in general tendency to indorse information, or in response bias, over time.

To address this possibility, we first examined how false alarms to new pairs changed over time. Mixed ANOVA on false alarm rates to new pairs with delay (Day 2 vs. Day 8) and age group (younger vs. older adults) revealed a significant effect of age group, $F(1, 51) = 9.72$, $p = .003$, $\eta_p^2 = 0.16$. The effects of delay, $F(1, 51) = 0.88$, $p = .35$, $\eta_p^2 = 0.02$, as well as the interaction between delay and age group were not significant, $F(1, 51) = 1.83$, $p = .18$, $\eta_p^2 = 0.04$. These results indicate that while false alarm rates to new pairs were generally higher in older adults ($M_{Day\ 2} = .04$, $SD_{Day\ 2} = .05$; $M_{Day\ 8} = .06$, $SD_{Day\ 2} = .05$) than in younger adults ($M_{Day\ 2} = .02$, $SD_{Day\ 2} = .03$; $M_{Day\ 8} = .02$, $SD_{Day\ 2} = .02$), these effects were not modulated by delay.
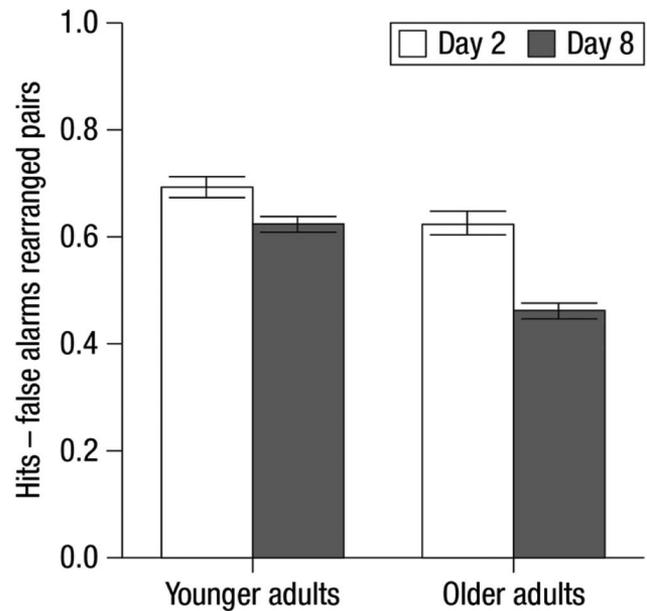

Figure 2. Associative memory on Day 2 and Day 8 for younger and older adults. Overall recognition performance measured as the discrimination index Pr on Day 2 (light bars) and Day 8 (dark bars). Error bars represent ± *SEM*.

Second, we computed the bias index using new pairs presented on Day 2 and Day 8 to assess changes in the tendency to respond "old" across age groups. The bias index based on the two high-threshold model was computed as $Br =$ False Alarm Rate$_{new\ pairs}/(1 − [Hit$ Rate$_{target\ pairs}$ − False Alarm Rate$_{new\ pairs}])$ (Snodgrass & Corwin, 1988). Values of Br >0.5 are generally considered to indicate a liberal bias. A mixed ANOVA on the bias index with delay (Day 2 vs. Day 8) and age group (younger vs. older adults) revealed a significant effect of age group, $F(1, 51) = 7.76$, $p = .007$, $\eta_p^2 = 0.13$, due to the overall higher Br values in older adults (Br$_{Day\ 2}$ $M = 0.17$, $SD = 0.18$, Br$_{Day\ 8}$ $M = 0.17$, $SD = 0.17$) compared with younger adults (Br$_{Day\ 2}$ $M = 0.08$, $SD = 0.14$, Br$_{Day\ 8}$ $M = 0.05$, $SD = 0.08$). Critically, the main effect of delay, $F(1, 51) = 1.01$, $p = .32$, $\eta_p^2 = 0.02$, as well as the interaction between delay and age group were not significant, $F(1, 51) = 0.86$, $p = .36$, $\eta_p^2 = 0.02$, suggesting that age-related differences in recognition memory changes across shorter and longer delays are unlikely to be driven by changes in response bias over time.

Age Differences in Hits at Shorter and Longer Delays

Next, we examined age differences in hit rates at shorter delays and longer delays.

Hits on Day 2. We performed a mixed ANOVA on hits on Day 2 with factors memory fidelity (high vs. low) and age group (younger vs. older adults). There was a significant effect of fidelity, $F(1, 51) = 195.58$, $p < .001$, $\eta_p^2 = .79$, suggesting that both age groups demonstrated higher memory for high- than for low-fidelity pairs (Figure 3A). There were no significant effects of age group, $F(1, 51) = 0.10$, $p = .75$, $\eta_p^2 = .002$, or a fidelity-by-age-group interaction, $F(1, 51) = 0.19$, $p = .66$, $\eta_p^2 = .004$.
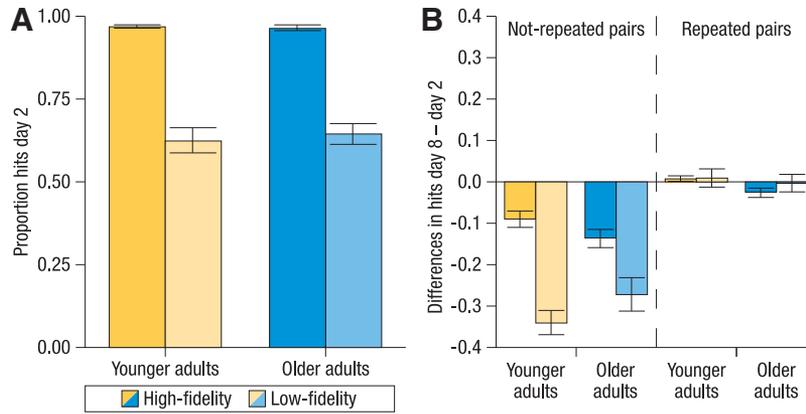
Figure 3. Hits on Day 2 and Day 8, separated by initial memory fidelity. (A) Proportion of hits for high-fidelity (darker colors) and low-fidelity (lighter colors) pairs on Day 2 across younger and older adults. (B) Differences in hits on Day 8 relative to Day 2 for high-fidelity (darker colors) and low-fidelity pairs (lighter colors) tested on Day 8 only (left; not-repeated pairs) and those tested on both Day 2 and Day 8 (right; repeated pairs). Error bars represent ± *SEM*. See the online article for the color version of this figure.

Next, we examined how hit rates changed over time. To examine the effects of decay, we compared hits on Day 2 to hits on Day 8 for target pairs encountered only on Day 8. We refer to this condition as *not-repeated pairs* below. To examine the effects of representational overlap through repeated exposure, we compared hits on Day 2 with hits on Day 8 for the same exact target pairs they encountered on Day 2 as well. Below, we refer to the target pairs that were tested on Day 8 as well as on Day 2 as *repeated pairs*. To facilitate presentation of the results, the dependent variable in these analyses was the change in hits on Day 8 compared with Day 2 for the corresponding fidelity type (see Figure 3B).

Hits on Day 8 compared with Day 2. An ANOVA on change in hits on Day 8 relative to Day 2 with initial fidelity (low vs. high), pair type (repeated vs. not-repeated), and age group (younger vs. older adults) revealed significant effects of pair type, $F(1, 51) = 274.23$, $p < .001$, $\eta_p^2 = 0.84$, and initial fidelity, $F(1, 51) = 21.87$, $p < .001$, $\eta_p^2 = 0.30$ (Figure 3B). The interaction between initial fidelity and pair type was also significant, $F(1, 51) = 69.004$, $p < .001$, $\eta_p^2 = .58$, such that presentation of the same intact pairs on Day 2 resulted in preservation of performance in both age groups for repeated pairs on Day 8 (Figure 3B), and this effect was more pronounced for high-fidelity pairs. Neither the effect of age group, $F(1, 51) = 0.09$, $p = .77$, $\eta_p^2 = 0.002$, nor the interaction between age group, pair type, and initial fidelity, $F(1, 51) = 3.52$, $p = .07$, $\eta_p^2 = 0.07$, were significant. Thus, we did not find evidence for age differences in how hit rates changes over time across conditions.

Age Differences in False Alarms at Shorter and Longer Delays

Next, we examined age differences in associative memory errors at shorter and longer delays depending on memory fidelity.

False alarms on Day 2. First, we performed a mixed ANOVA on false alarms to rearranged pairs on Day 2 with memory fidelity (high vs. low) and age group (younger vs. older adults). There was a significant main effect of fidelity, $F(1, 51) = 79.14$, $p < .001$, $\eta_p^2 = .61$, such that both groups committed more false alarms for low- than for high-fidelity pairs (Figure 4A). There was also a main effect of age group, $F(1, 51) = 6.99$, $p = .01$, $\eta_p^2 = .12$, indicating that older adults were overall more likely to falsely claim that a rearranged pair has been seen before (Figure 4A). The interaction between fidelity and age group was not significant $F(1, 51) = 0.09$, $p = .77$, $\eta_p^2 = .002$.

Next, we examined how false alarms changed over time. Here, we were particularly interested in determining how decay and representational overlap affected false alarms in younger and older adults. To examine the effects of decay, we examined age differences for not-repeated pairs. To examine the effects of representational overlap, we examined age differences in repeated pairs. Similar to the results for hit rates, to facilitate presentation of the results, the dependent variable in these analyses was the change in false alarms on Day 8 compared with Day 2 for the corresponding fidelity type (see Figure 4B).

Differences in false alarms on Day 8 compared with Day 2. We performed a mixed ANOVA on the difference between false alarms to rearranged pairs on Day 8 minus false alarms to rearranged pairs on Day 2 with memory fidelity (low vs. high), pair type (repeated vs. not-repeated), and age group (younger vs. older adults). There was a main effect of age group, $F(1, 51) = 9.39$, $p = .003$, $\eta_p^2 = .16$, indicating an overall greater increase in false alarms from Day 2 to Day 8 in older adults (Figure 4B). There was also a main effect of pair type, $F(1, 51) = 96.02$, $p < .001$, $\eta_p^2 = .65$, indicating that false memory increased more for repeated pairs than not-repeated pairs that were tested only on Day 8 (Figure 4B). We also found a main effect of fidelity, $F(1, 51) = 23.33$, $p < .001$, $\eta_p^2 = .31$, and a three-way interaction between age group, condition, and fidelity, $F(1, 51) = 5.89$, $p = .019$, $\eta_p^2 = .10$. To unpack these effects, we examined how age and memory fidelity influenced change in false alarms between Day 2 and Day 8 separately for repeated and not-repeated pairs.
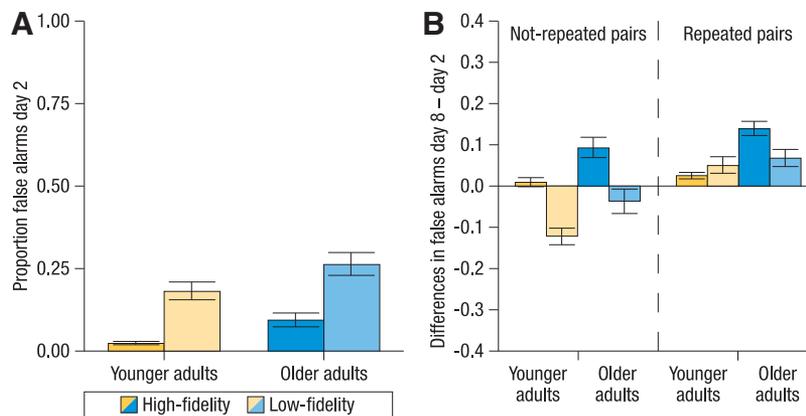
Figure 4. False alarms to rearranged pairs on Day 2 and Day 8, separated by initial memory fidelity. (A) Proportion of false alarms for high-fidelity (darker colors) and low-fidelity (lighter colors) pairs on Day 2 across younger and older adults. (B) Differences in false alarms on Day 8 relative to Day 2 for high-fidelity (darker colors) and low-fidelity pairs (lighter colors) tested on Day 8 only (left; not-repeated pairs) and those tested on both Day 2 and Day 8 (right; repeated pairs). Error bars represent ± *SEM*. See the online article for the color version of this figure.

Differences in false alarms on Day 8 compared with Day 2: Not-repeated pairs. We performed a mixed ANOVA on the difference in false alarms for not-repeated pairs that were tested only on Day 8 compared with rearranged false alarms on Day 2 with fidelity (high vs. low) and age group (younger vs. older adults) as factors. There was a main effect of fidelity, $F(1, 51) = 36.60, p < .001, \eta_p^2 = .42$. False alarms to high-fidelity pairs were similar or even more frequent when tested after a long delay on Day 8 than after a short delay on Day 2 (Figure 4B). In contrast, false alarms to low-fidelity pairs were actually rarer when tested after a long delay relative to a short delay in both younger and older adults (Figure 4B). The main effect of age group was significant, $F(1, 51) = 13.61, p < .001, \eta_p^2 = .21$, consistent with the greater increase in false alarms in older adults over time. There interaction was not significant, $F(1, 51) = 0.002, p = .968, \eta_p^2 = .00$.

Differences in false alarms on Day 8 compared with Day 2: Repeated pairs. A mixed ANOVA on the difference in false alarms for repeated pairs that were tested on both days relative to rearranged false alarms on Day 2 with factors fidelity (high vs. low) and age group (younger vs. older adults) yielded a significant effect of age group, $F(1, 51) = 12.53, p = .001, \eta_p^2 = .197$, consistent with the results above showing a greater increase in memory errors in older adults over time (see also Figure 4B). The main effect of fidelity was not significant, $F(1, 51) = 2.17, p = .147, \eta_p^2 = .04$. Finally, there was a significant interaction between fidelity and age group, $F(1, 51) = 9.52, p = .003, \eta_p^2 = .16$. Post hoc tests revealed that younger and older adults showed similar increases in low-fidelity false alarms for repeated pairs on Day 8 (Figure 4B), $t(51) = 0.61, p_{corr} = .54, d = .17$. In contrast, false alarms to high-fidelity pairs showed a greater increase in older than in younger adults, $t(51) = 6.15, p_{corr} < .001, d = 1.68$ (Figure 4B).

Additional Analyses of Memory Transitions Over Time

In the representational overlap condition, participants encountered rearranged pairs on both Day 2 and Day 8, and made old/new decisions on these pairs on both days. Here, Day 2 recognition success may have affected the likelihood to incorrectly endorse rearranged pairs on Day 8. We performed control analyses to compare the proportion of false alarms on Day 2 that remained false alarms on Day 8 and the proportion of correct rejections on Day 2 that transitioned into false alarms on Day 8. A mixed ANOVA with transition (false–false vs. correct–false) and age group (younger vs. older adults) demonstrated a significant effect of transition, $F(1, 51) = 22.816, p < .001, \eta_p^2 = .31$, along with a reliable interaction between transition and age group, $F(1, 51) = 9.23, p = .004, \eta_p^2 = .15$. False alarms on Day 2 were generally likely to remain false alarms in younger, $M = .61, SD = .28$, and older adults, $M = .55, SD = .17, t(51) = 0.91, p_{corr} = .37, d = 0.22$. Fewer correct rejections on Day 2 transitioned to false alarms on Day 8 for younger, $M = .09, SD = .05$, than for older adults, $M = .24, SD = .10, t(51) = 6.64, p_{corr} < .001, d = 1.90$.

What might contribute to this higher transition likelihood in older adults? One possibility is that the transitioning pairs were less confident correct rejections on Day 2 in the first place (i.e., guesses), making the original memory trace more susceptible to integration with the presented rearranged information on Day 2. If so, rearranged pairs transitioning from correct to false response between Day 2 and Day 8 would be endorsed with lower confidence on Day 2. To test this, we examined the level of confidence for correct rejections on Day 2 based on whether they subsequently remained correct rejections or transitioned to false alarms on Day 8. A mixed ANOVA on Day 2 confidence judgments by transition (correct–correct vs. correct–false) and age group (younger vs. older adults) revealed a main effect of transition, $F(1, 51) = 20.59, p < .001, \eta_p^2 = .29$, along with significant interaction between transition and age group, $F(1, 51) = 13.15, p = .001, \eta_p^2 = .21$. The effect of age group was not significant, $F(1, 51) = 0.15, p = .70, \eta_p^2 = .003$. Differences in confidence between younger and older adults were minimal for correct–correct transitions, $t(51) = 2.04, p_{corr} = .05, d = 0.57$, with older adults, $M = 3.32, SD = 0.45$, showing slightly *lower* confidence than younger adults, $M = 3.53, SD = 0.27$. By contrast, older adults reported

higher confidence on Day 2 for correct rejections that later became false alarms, $M = 3.10$, $SD = 0.55$, than did younger adults, $M = 2.79$, $SD = 0.67$, $t(51) = 2.85$, $p_{corr} = .01$, $d = .51$. Together, these exploratory analyses suggest that correctly rejected rearranged pairs that were later falsely remembered were associated with lower confidence on Day 2 in younger adults, whereas confidence was not predictive of the future fate of the rearranged pair in older adults.

Discussion

This study provides novel evidence that age differences in memory errors persist and become magnified over time such that older adults demonstrate an even greater susceptibility to associative memory errors when tested after longer delays. Compared with younger adults, we found that older adults' associative memory was further reduced 8 days after learning compared with 24 hr after learning. This finding is consistent with the greater loss of associative information in older adults shown by Mary, Schreiner, and Peigneux (2013) and contributes to an ongoing debate whether aging is associated with accelerated long-term forgetting (e.g., Elliott et al., 2014). Separate analyses of hits and false alarms revealed that while the effects of delay on hit rates were similar across age groups, older adults demonstrated an increased propensity to wrongly remember unstudied associations at longer delays. This finding points to a more nuanced picture of age differences in forgetting which may be especially pronounced for associative information akin to episodic memory and may be easily missed when only item memory is examined. Future research directly comparing age differences in forgetting for item versus associative information (Naveh-Benjamin, 2000) and peripheral versus central details (Sekeres et al., 2016) along with using different types of stimuli can help arrive at a better understanding of the mechanisms underlying forgetting in later adulthood.

Whereas previous research has suggested that decay and representational overlap are the major sources of changes in the quality of mnemonic information over time (Hardt et al., 2013; Roediger et al., 2010; Sadeh et al., 2014), to the best of our knowledge no research has examined how these factors modulate age differences in associative memory. In the present study we therefore examined how decay and representational overlap contribute to age differences in associative memory errors. We discuss each of these factors below.

Effects of Delay on Age Differences in Associative Memory Errors

Previous research has shown that associative memory fidelity critically influences older adults' propensity for memory errors when tested 24 hr after encoding (Fandakova et al., 2018). Here, we extended the delay to 8 days. For high-fidelity associations, we found that false alarms remained stable or increased after 8 days relative to 24 hr after initial learning in both age groups. These results resonate with false memory research using the Deese-Roediger-McDermott paradigm in younger adults, which suggests that false alarms may be more persistent over time than patterns of correct responses (e.g., Seamon et al., 2002). In contrast, errors for low-fidelity associations actually *decreased* over time in both younger and older adults. Along with the decreases for hits that

were comparable between younger and older adults, the present results indicate that in the absence of strong representational overlap loss of information over time is similar in younger and older adults.

Critically, the present results underscore that for both age groups decay effects on associative memory are not uniform, but depend on the fidelity of the initially formed representation. Details, especially those not central to an event, are more likely to be forgotten over time in younger adults (Sekeres et al., 2016). Therefore, we speculated that memory fidelity would decrease over time. As a result, initially high-fidelity associative memories would become more similar to low-fidelity memories, whereas initially low-fidelity memories would decline, potentially rendering those pairs inaccessible or lost during retrieval (e.g., Habib & Nyberg, 2008). Memory errors are less likely at both ends of the continuum of memory fidelity: They are highly unlikely for well-learned associations (Fandakova et al., 2018; Rotello, Macmillan, & Van Tassel, 2000) but also when the memory trace is weak or mnemonic evidence does not suffice. In the case of completely new information as an extreme example, novelty can even facilitate responses and help to avoid memory errors (e.g., Dobbins, Kroll, Yonelinas, & Liu, 1998; Tulving & Kroll, 1995). Our finding of reduced memory errors for low-fidelity pairs indicates that these pairs further lose fidelity across time, reducing the probability for false claims that recombined information was old. In line with this interpretation, low-fidelity hits showed pronounced decreases over time in both age groups. Together, our results suggest that the effect of fidelity on memory error likelihood may follow an inverted U-shape with a maximum when some (unknown) familiarity threshold is reached (see Figure 5). Accordingly, the effect of decay with time simply results in a shift of associative memories across the inverted U-shape relating false alarms and fidelity.

Effects of Representational Overlap on Age Differences in Associative Memory Errors

Memory traces do not only passively decay over time. Rather, mnemonic information is modified when we experience similar events, resulting in overlapping representations and increased interference (Roediger et al., 2010). In this study, we simulated the daily experience of similar events by testing rearrangements of some of the scene–word pairs at two time points. Similar to previous findings with the misinformation paradigm (Loftus, 2005), we expected this manipulation to increase representational overlap between the initially learned scene–word pairs and the rearranged pairs, thereby also increasing potential interference at retrieval.

In younger adults, we found that presenting similar information in the form of rearranged pairs on Day 2 had stronger effects on low-fidelity memories that are thought to be more susceptible to integrating new erroneous information during the test on Day 2. In contrast, younger adults showed minimal increases in memory errors for high-fidelity pairs, suggesting that a well-bound representation is resilient to representational overlap. This finding is in line with suggestions by Sadeh, Ozubko, Winocur, and Moscovitch (2014) that interference effects depend on the fidelity of the underlying initial memory trace.
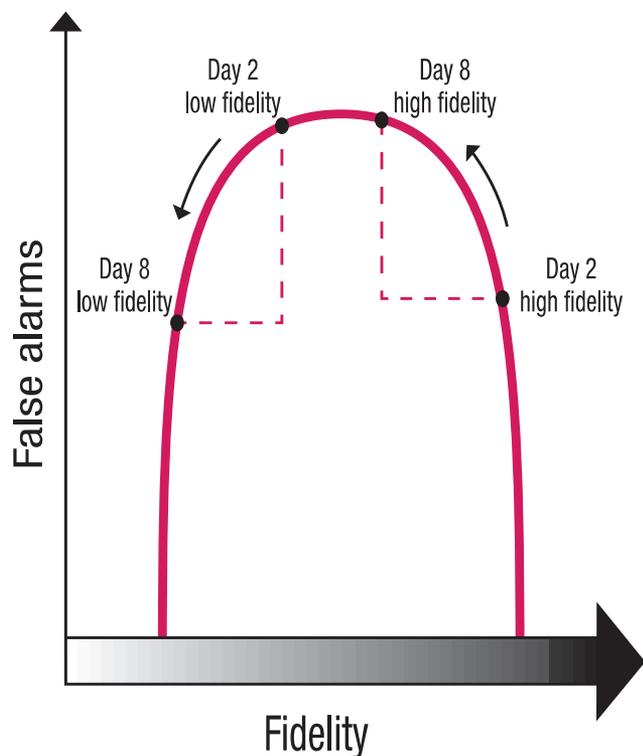
Figure 5. Schema of how longer versus shorter delays may affect the level of fidelity for a given memory representation and thereby modulate false associative memory. See the online article for the color version of this figure.

A different pattern of results emerged in older adults. Older adults' false alarms for low-fidelity pairs increased with representational overlap, similarly to younger adults. At the same time, however, older adults showed a disproportionate increase in false alarms for high-fidelity pairs. These results corroborate previous research and provide a hint that age differences in underlying monitoring processes during retrieval contribute to differences in memory errors after short delays (e.g., Devitt & Schacter, 2016). In the present design, presenting rearranged pairs on Day 2 was expected to induce incorporation of erroneous information requiring more monitoring for successful interference resolution on Day 8. In line with previous work at shorter delays (Dulas & Duarte, 2016; Fandakova et al., 2018), we expected older adults to have more difficulties in successfully engaging monitoring processes, whereas younger adults' well-bound associative representations would be protected from interference. The results are in line with this expectation and suggest that the negative effects of age-related declines in monitoring processes on associative memory may be further augmented at longer delays.

The exploratory analysis of confidence ratings lends further support for this interpretation. Younger adults' correct rejections on Day 2 that transitioned to false alarms on Day 8 were associated with lower subjective confidence, potentially reflecting the relative lack of mnemonic evidence compared with pairs that were correctly rejected on both days. No such effects were observed in older adults where confidence judgments did not differentiate between correct rejections on Day 2 that remained, or transitioned

to false alarms on Day 8. This result is consistent with findings that age-related monitoring deficits at retrieval are associated with miscalibrated confidence judgments in older adults (Dodson, Bawa, & Krueger, 2007; Fandakova et al., 2013; Shing, Werkle-Bergner, Li, & Lindenberger, 2009). Interestingly, confidence may initiate further information seeking in decision-making (e.g., Desender, Boldt, & Yeung, 2018) or during self-guided learning (e.g., Bjork, Dunlosky, & Kornell, 2013). Thus, Day 2 confidence judgments may potentially tag information for retention in its modified form.

It should be noted that the effects of representational overlap in the present study are not independent of the effects of decay described above, but are rather complementary to them (Roediger et al., 2010). To better understand how decay and representational overlap dynamically interact and affect memory at longer delays, future studies should address the effects of interference when overlapping information is presented at different points during the delay. In this context, the present results highlight that the effects of presenting overlapping information critically depend on the fidelity of the initial information.

Finally, while the present results indicate that monitoring deficits contribute to older adults' difficulties in resolving interference with representational overlap over time, deficits in these processes were not measured directly. Moreover, increases in item familiarity can also, at least partially, contribute to the increased demands to monitor the source of the familiarity signal. Future research combining behavioral manipulations with changes in the underlying neural circuits over extended delays can help shed more direct light on the involvement of these processes. Based on our previous results (Fandakova et al., 2018; see also Fandakova et al., 2014), we expect that older adults will show less modulation of cingulo-opercular and lateral prefrontal regions over time, especially in the representational overlap condition.

Conclusion

Taken together, our results suggest that testing associative memory after longer delays reveals a double jeopardy for older adults: First, they are more likely to find themselves in situations with greater similarities between episodes that increase interference resolution demands. Furthermore, age-related declines in monitoring processes impair older adults' effective interference resolution, thereby raising future false memory likelihood. Older adults are thus particularly vulnerable to misremembering episodes and their features over time. Our findings highlight the necessity to find effective ways to increase memory fidelity and to structure older adults' environment in ways that decrease demands on monitoring.

References

Benjamin, A. S. (2010). Representational explanations of "process" dissociations in recognition: The DRYAD theory of aging and memory judgments. *Psychological Review, 117,* 1055–1079. http://dx.doi.org/10.1037/a0020810

Bjork, R. A., Dunlosky, J., & Kornell, N. (2013). Self-regulated learning: Beliefs, techniques, and illusions. *Annual Review of Psychology, 64,* 417–444. http://dx.doi.org/10.1146/annurev-psych-113011-143823

Desender, K., Boldt, A., & Yeung, N. (2018). Subjective confidence predicts information seeking in decision making. *Psychological Science, 29,* 761–778. http://dx.doi.org/10.1177/0956797617744771

Devitt, A. L., & Schacter, D. L. (2016). False memories with age: Neural and cognitive underpinnings. *Neuropsychologia, 91,* 346–359. http://dx .doi.org/10.1016/j.neuropsychologia.2016.08.030

Dobbins, I. G., Kroll, N. E. A., Yonelinas, A. P., & Liu, Q. (1998). Distinctiveness in recognition and free recall: The role of recollection in the rejection of the familiar. *Journal of Memory and Language, 38,* 381–400. http://dx.doi.org/10.1006/jmla.1997.2554

Dodson, C. S. (2017). Aging and memory. In J. H. Byrne (Ed.), *Learning and memory: A comprehensive reference* (2nd ed., pp. 403–421). Oxford, UK: Academic Press. http://dx.doi.org/10.1016/B978-0-12-809324-5.21053-5

Dodson, C. S., Bawa, S., & Krueger, L. E. (2007). Aging, metamemory, and high-confidence errors: A misrecollection account. *Psychology and Aging, 22,* 122–133. http://dx.doi.org/10.1037/0882-7974.22.1.122

Dulas, M. R., & Duarte, A. (2016). Age-related changes in overcoming proactive interference in associative memory: The role of PFC-mediated executive control processes at retrieval. *NeuroImage, 132,* 116–128. http://dx.doi.org/10.1016/j.neuroimage.2016.02.017

Eichenbaum, H., & Cohen, N. J. (2001). *From conditioning to conscious recollection memory systems of the brain.* New York, NY: Oxford University Press.

Elliott, G., Isaac, C. L., & Muhlert, N. (2014). Measuring forgetting: A critical review of accelerated long-term forgetting studies. *Cortex, 54,* 16–32. http://dx.doi.org/10.1016/j.cortex.2014.02.001

Fandakova, Y., Lindenberger, U., & Shing, Y. L. (2014). Deficits in process-specific prefrontal and hippocampal activations contribute to adult age differences in episodic memory interference. *Cerebral Cortex, 24,* 1832–1844. http://dx.doi.org/10.1093/cercor/bht034

Fandakova, Y., Sander, M. C., Grandy, T. H., Cabeza, R., Werkle-Bergner, M., & Shing, Y. L. (2018). Age differences in false memory: The importance of retrieval monitoring processes and their modulation by memory quality. *Psychology and Aging, 33,* 119–133. http://dx.doi.org/ 10.1037/pag0000212

Fandakova, Y., Shing, Y. L., & Lindenberger, U. (2013). High-confidence memory errors in old age: The roles of monitoring and binding processes. *Memory, 21,* 732–750. http://dx.doi.org/10.1080/09658211.2012 .756038

Farias, S. T., Mungas, D., & Jagust, W. (2005). Degree of discrepancy between self and other-reported everyday functioning by cognitive status: Dementia, mild cognitive impairment, and healthy elders. *International Journal of Geriatric Psychiatry, 20,* 827–834. http://dx.doi.org/ 10.1002/gps.1367

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12,* 189–198. http://dx .doi.org/10.1016/0022-3956(75)90026-6

Fritsch, T., McClendon, M. J., Wallendal, M. S., Hyde, T. F., & Larsen, J. D. (2014). Prevalence and cognitive bases of subjective memory complaints in older adults: Evidence from a community sample. *Journal of Neurodegenerative Diseases.* Advance online publication. http://dx .doi.org/10.1155/2014/176843

Giovanello, K. S., & Schacter, D. L. (2012). Reduced specificity of hippocampal and posterior ventrolateral prefrontal activity during relational retrieval in normal aging. *Journal of Cognitive Neuroscience, 24,* 159–170. http://dx.doi.org/10.1162/jocn_a_00113

Gutchess, A. H., Hebrank, A., Sutton, B. P., Leshikar, E., Chee, M. W. L., Tan, J. C., . . . Park, D. C. (2007). Contextual interference in recognition memory with age. *NeuroImage, 35,* 1338–1347. http://dx.doi.org/10 .1016/j.neuroimage.2007.01.043

Habib, R., & Nyberg, L. (2008). Neural correlates of availability and accessibility in memory. *Cerebral Cortex, 18,* 1720–1726. http://dx.doi .org/10.1093/cercor/bhm201

Hardt, O., Nader, K., & Nadel, L. (2013). Decay happens: The role of active forgetting in memory. *Trends in Cognitive Sciences, 17,* 111–120. http://dx.doi.org/10.1016/j.tics.2013.01.001

Hertzog, C., Hülür, G., Gerstorf, D., & Pearman, A. M. (2018). Is subjective memory change in old age based on accurate monitoring of age-related memory change? Evidence from two longitudinal studies. *Psychology and Aging, 33,* 273–287. http://dx.doi.org/10.1037/pag0000232

Li, S.-C., Naveh-Benjamin, M., & Lindenberger, U. (2005). Aging neuro-modulation impairs associative binding: A neurocomputational account. *Psychological Science, 16,* 445–450.

Loftus, E. F. (2005). Planting misinformation in the human mind: A 30-year investigation of the malleability of memory. *Learning & Memory, 12,* 361–366. http://dx.doi.org/10.1101/lm.94705

Mary, A., Schreiner, S., & Peigneux, P. (2013). Accelerated long-term forgetting in aging and intra-sleep awakenings. *Frontiers in Psychology, 4,* 750. http://dx.doi.org/10.3389/fpsyg.2013.00750

Mitchell, K. J., & Johnson, M. K. (2009). Source monitoring 15 years later: What have we learned from fMRI about the neural mechanisms of source memory? *Psychological Bulletin, 135,* 638–677. http://dx.doi .org/10.1037/a0015849

Muehlroth, B. E., Sander, M. C., Fandakova, Y., Grandy, T. H., Rasch, B., Shing, Y. L., & Werkle-Bergner, M. (2019). Precise slow oscillation-spindle coupling promotes memory consolidation in younger and older adults. *Scientific Reports, 9,* 1940. http://dx.doi.org/10.1038/s41598-018-36557-z

Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1170–1187. http://dx.doi.org/10.1037/0278-7393.26.5.1170

Old, S. R., & Naveh-Benjamin, M. (2008). Differential effects of age on item and associative measures of memory: A meta-analysis. *Psychology and Aging, 23,* 104–118. http://dx.doi.org/10.1037/0882-7974.23.1.104

Park, D. C., Puglisi, J. T., & Smith, A. D. (1986). Memory for pictures: Does an age-related decline exist? *Psychology and Aging, 1,* 11–17.

Roediger, H. L., III, Weinstein, Y., & Agarwal, P. K. (2010). Forgetting: Preliminary considerations. In Sergio Della Sala (Ed.), *Forgetting* (pp. 15–36). London, UK: Psychology Press.

Rotello, C. M., Macmillan, N. A., & Van Tassel, G. (2000). Recall-to-reject in recognition: Evidence from ROC curves. *Journal of Memory and Language, 43,* 67–88. http://dx.doi.org/10.1006/jmla.1999.2701

Rugg, M. D. (2004). Retrieval processing in human memory: Electrophysiological and fMRI evidence. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 727–737). Cambridge, MA: MIT Press.

Sadeh, T., Ozubko, J. D., Winocur, G., & Moscovitch, M. (2014). How we forget may depend on how we remember. *Trends in Cognitive Sciences, 18,* 26–36. http://dx.doi.org/10.1016/j.tics.2013.10.008

Sadeh, T., Ozubko, J. D., Winocur, G., & Moscovitch, M. (2016). Forgetting patterns differentiate between two forms of memory representation. *Psychological Science, 27,* 810–820. http://dx.doi.org/10.1177/ 0956797616638307

Seamon, J. G., Luo, C. R., Kopecky, J. J., Price, C. A., Rothschld, L., Fung, N. S., & Schwartz, M. A. (2002). Are false memories more difficult to forget than accurate memories? The effect of retention interval on recall and recognition. *Memory & Cognition, 30,* 1054–1064. http://dx.doi .org/10.3758/BF03194323

Sekeres, M. J., Bonasia, K., St-Laurent, M., Pishdadian, S., Winocur, G., Grady, C., & Moscovitch, M. (2016). Recovering and preventing loss of detailed memory: Differential rates of forgetting for detail types in episodic memory. *Learning & Memory, 23,* 72–82. http://dx.doi.org/10 .1101/lm.039057.115

Shing, Y. L., Werkle-Bergner, M., Brehmer, Y., Müller, V., Li, S. C., & Lindenberger, U. (2010). Episodic memory across the lifespan: The contributions of associative and strategic components. *Neuroscience and*

Biobehavioral Reviews, 34, 1080–1091. http://dx.doi.org/10.1016/j.neubiorev.2009.11.002

Shing, Y. L., Werkle-Bergner, M., Li, S. C., & Lindenberger, U. (2008). Associative and strategic components of episodic memory: A life-span dissociation. *Journal of Experimental Psychology: General, 137,* 495–513. http://dx.doi.org/10.1037/0096-3445.137.3.495

Shing, Y. L., Werkle-Bergner, M., Li, S. C., & Lindenberger, U. (2009). Committing memory errors with high confidence: Older adults do but children don't. *Memory, 17,* 169–179. http://dx.doi.org/10.1080/09658210802190596

Snodgrass, J. G., & Corwin, J. (1988). Pragmatics of measuring recognition memory: Applications to dementia and amnesia. *Journal of experimental psychology: General, 117,* 34–50.

Sommer, V. R., Fandakova, Y., Grandy, T. H., Shing, Y. L., Werkle-Bergner, M., & Sander, M. C. (2019). Neural pattern similarity differentially relates to memory performance in younger and older adults. *The Journal of Neuroscience, 39,* 8089–8099. http://dx.doi.org/10.1523/JNEUROSCI.0197-19.2019

Spencer, W. D., & Raz, N. (1995). Differential effects of aging on memory for content and context: A meta-analysis. *Psychology and Aging, 10,* 527–539. http://dx.doi.org/10.1037/0882-7974.10.4.527

Tulving, E., & Kroll, N. (1995). Novelty assessment in the brain and long-term memory encoding. *Psychonomic Bulletin & Review, 2,* 387–390. http://dx.doi.org/10.3758/BF03210977

Winocur, G., & Moscovitch, M. (2011). Memory transformation and systems consolidation. *Journal of the International Neuropsychological Society, 17,* 766–780. http://dx.doi.org/10.1017/S1355617711000683

Yang, J., Zhan, L., Wang, Y., Du, X., Zhou, W., Ning, X., . . . Moscovitch, M. (2016). Effects of learning experience on forgetting rates of item and associative memories. *Learning & Memory, 23,* 365–378. http://dx.doi.org/10.1101/lm.041210.115

Yassa, M. A., & Reagh, Z. M. (2013). Competitive trace theory: A role for the hippocampus in contextual interference during retrieval. *Frontiers in Behavioral Neuroscience, 7,* 107. http://dx.doi.org/10.3389/fnbeh.2013.00107

Zaragoza, M. S., & Mitchell, K. J. (1996). Repeated exposure to suggestion and the creation of false memories. *Psychological Science, 7,* 294–300. http://dx.doi.org/10.1111/j.1467-9280.1996.tb00377.x

---

E-Mail Notification of Your Latest Issue Online!

Would you like to know when the next issue of your favorite APA journal will be available online? This service is now available to you. Sign up at https://my.apa.org/portal/alerts/ and you will be notified by e-mail when issues of interest to you become available!