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Flexible Retrieval Mechanisms Supporting Successful Inference Produce False Memories in Younger but not Older Adults

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Abstract

Episodic memory involves flexible retrieval processes that allow us to link elements of distinct episodes in order to make novel inferences across events. In younger adults, we recently found that the same retrieval-related recombination mechanism that supports successful associative inference produces source misattributions as a consequence of erroneous binding of contextual elements from distinct episodes. In the current experiment, we found that older adults, in contrast to younger adults, did not show an increase in source misattributions following successful associative inference. We observed this pattern both when (A) younger and older adults were tested under identical experimental conditions, and (B) younger and older adults were matched on associative inference accuracy and overall source memory errors. We suggest that the differing patterns of results are a consequence of age-related deficits in associative binding during successful inferential retrieval.

Keywords

Aging; Inference; False Memory; Episodic Memory; Associative Processes

Age-related deficits in associative binding are well established across a range of tasks and conditions (e.g., Castel & Craik, 2003; Cohn, Emrich, & Moscovitch, 2008; Old & Naveh-Benjamin, 2008; Smyth & Naveh-Benjamin, 2016). For example, older adults compared to younger adults are just as able to remember colors and objects that they had previously learned but perform poorly when they are required to bind those two pieces of information together. That is, when older adults were tested on the color in which the target object had appeared during the study phase, older adults performed worse compared to younger adults (Chalfonte & Johnson, 1996). These results suggest that older adults have special difficulty binding pieces of information into complex memories. Age-related difficulties in associative binding are thought to reflect older adults' inability to form and retrieve links among single bits of information. A meta-analysis of age-related associative deficits (Old & Naveh-Benjamin, 2008) suggests that this deficit applies to memory for two bound items (e.g., face-name pairs; Naveh-Benjamin, Guez, Kilb & Reedy, 2004), in addition to memory for source (e.g., which of two speakers presented a fact; Schacter, Kaszniak, Kihlstrom & Valdiserri, 1991), context (e.g., the font that a word was presented in; Kausler & Puckett, 1980),

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temporal order (e.g., which word was presented first; Newman, Allen & Kaszniak, 2001) and location information (e.g., where on the screen an item was presented; Bastin & Van der Linden, 2006).

Such age-related deficits are also relevant to situations in which people need to recombine bits of stored information to construct novel representations. For example, older adults typically construct less detailed representations of novel future events than do younger adults (for review, see Schacter, Gaesser, & Addis, 2013), and this age-related reduction has been attributed, in part, to problems recombining different kinds of episodic details into a cohesive imagined event (e.g., Addis, Musicaro, Pan, & Schacter, 2010).

According to the constructive episodic simulation hypothesis (Schacter & Addis, 2007), the ability to flexibly recombine episodic details into a novel event representation is an adaptive process that depends on relational or associative processing abilities, but can also result in memory errors when elements of past experiences are mistakenly combined. In recent experiments with young adults, Carpenter and Schacter (2017) tested this idea using an adapted version of an *associative inference* task established by Preston and colleagues (e.g., Zeithamova & Preston, 2010). Associative inference allows one to link together information acquired in distinct episodes in order to make novel connections that they have not directly experienced. In our procedure, participants initially study scenes that include AB pairs (e.g., a person (‘A’) and a toy (‘B’) in a room with a white couch) and then study scenes comprised of BC pairs (e.g., the toy (‘B’) and a different person (‘C’) in a room with a brown couch; see Figure 1). After a delay, participants are tested on the directly learned associations (AB, BC) and are also given an associative inference test for novel combinations, not previously presented together, that are linked via the shared B item (AC).

To determine whether recombination processes underlying successful inference contribute to memory errors, memory for contextual details from both the AB and BC scenes is probed (e.g., What color was the couch?), along with source memory (In which set of images do you remember seeing this information?). For one half of the AB and BC scenes, detail/source memory tests were given *before* the test of direct (AB, BC) and indirect (AC) associations, and for the other half, the detail/source memory tests were given *after* tests of direct and indirect associations. For the detail/source test, a *true memory* is defined as a response in which the participants both chose the correct item and attributed the source of their memory correctly (e.g., white couch attributed to AB scene), whereas a *false memory* is defined as a response for which participants both chose the item from the overlapping image (BC) and misattributed its source to the currently cued image (e.g., brown couch attributed to AB scene; see Figure 1).

In each of four experiments, participants made more source memory errors for items from triads for which they made *correct* compared to *incorrect* associative inferences, but this increase occurred only when the detail/source test was given *after* the associative inference test; there was no difference in source memory errors as a function of correct vs. incorrect inferences when the detail/source test was given *before* the associative inference test. We argued that this pattern of results indicates that the same flexible recombination process that produces successful associative inferences also produces false memories as a consequence of erroneous binding of elements from distinct episodes.

In the present experiment, we ask whether this same pattern of results is observed in older adults. Numerous previous experiments have established that older adults are frequently more prone than young adults to various kinds of false memory effects involving source misattributions (for a recent review, see Devitt & Schacter, 2016). Poor associative binding of item information to its respective context or source has been linked to increased susceptibility to false memories in older adults, where details of one event are misremembered as having come from another event (Fandakova, Shing & Lindenberger, 2013; Lyle, Bloise & Johnson, 2006) and further may explain why susceptibility to source memory errors typically increases with age (Wylie et al., 2014). For example, when participants were asked to simulate counterfactual scenarios of past events, older adults compared to younger adults were more likely to mistake the counterfactual simulation for the original event (Gerlach, Dornblaser & Schacter, 2014). That is, older adults showed a reduction in binding perceptual and contextual features that were useful in determining the source of an experience, such that experiences from different sources (e.g., memory for the original event compared to simulation) were more similar in quality (Gerlach et al., 2014).

As a result, specific *details* from one context or source (e.g., simulated counterfactual) may also be misattributed to an incorrect source (e.g., memory for the original event). In line with this idea, past research suggests that if contextual information informing the source of the original or contradictory misinformation details is not fully bound with the appropriate memory representation, there is a greater likelihood that the misinformation detail will be falsely attributed to the incorrect source, in this case, participants' memory of the original event (Cohen & Faulkner, 1989; Dodson & Krueger, 2006; Dodson, Powers & Lytell, 2015). For example, when participants viewed a vignette depicting a robbery during which a necklace was stolen but were later misinformed that the item stolen was a ring, older adults were more likely than younger adults to remember *seeing* a ring stolen in the original event (Cohen & Faulkner, 1989; Dodson & Krueger, 2006; Dodson et al., 2015). Thus, one possibility is that older adults would be even more prone than younger adults to false memories resulting from successful associative inference due to an age-related reduction in the binding of contextual information (e.g., the color of the couch) to its correct source (i.e., the first or second set of images). As a result, in the current experiment older adults may be more likely to misattribute information, such as the color of the couch, from the AB image to their memory of the BC image once these two events are related following successful associative inference.

On the other hand, given extensive evidence of age-related decreases in associative binding (Old & Naveh-Benjamin, 2008; Smyth & Naveh-Benjamin, 2016), it is possible that when older adults make correct associative inferences, they do not reactivate and bind elements of distinct episodes as fully as younger adults, and thus would exhibit relatively fewer false memories after successful associative inference. This idea is consistent with recent findings suggesting that older adults show a reduced capacity to update memory in response to new information (Attali & Dalla Barba, 2013; St. Jacques, Montgomery, & Schacter, 2015). In the current associative inference paradigm, deficits in cross-episode associative binding and memory updating may actually prevent the formation of false memories following successful inference. That is, if older adults are able to infer the relationship between ‘A’ and ‘C’ via their shared association with ‘B’ but do not spontaneously 1) reactivate the contextual details associated with events ‘AB’ and ‘BC’ in as much detail as younger adults or 2) update their memory representation by fully binding items ‘A,’ ‘B’ and ‘C’ across episodes to form an integrated ABC event representation, older adults may be *less* likely than younger adults to incorrectly bind contextual elements from event ‘AB’ to their memory for event ‘BC.’

We tested these competing hypotheses by comparing the performance of old and young adults in two different ways: 1) under identical experimental conditions (i.e., a 24-hour study-test delay for both groups) and 2) under conditions in which the levels of associative inference performance and overall source memory errors were equated in young and old adults by testing young adults at a longer delay (48-hours). The latter comparison was needed because when young and old were tested under identical conditions, older adults showed lower overall levels of associative inference and source memory performance than young adults, thus potentially complicating the interpretation of the critical inference-dependent false memory results.

Results of the current experiment support the second of the two hypotheses outlined above. That is, younger adults showed a significant increase in false memories only following successful associative inference, whereas older adults showed no significant differences in false memories for successful compared to unsuccessful inference even when older adults’ overall source memory errors and associative inference performance were matched to younger adults.

Methods

Participants

A power analysis (Faul, Erdfelder, Lang & Buchner, 2007) based on effect sizes from our previous related work (Carpenter & Schacter, 2017) for the key predicted effect of interest revealed that a sample size of 20 would provide the ability to detect an effect on false memories after vs. before successful inference conditions with power of >.80. Thus, we aimed for a sample of 24 usable participants for each group. Twenty-five older adults were recruited from newspaper advertisements and community centers in the Boston area. All had normal vision and no history of neurological impairment. They gave informed consent, were treated in accordance with guidelines approved by the ethics committee at Harvard University, and were paid for completing the study. One older adult was excluded from all analyses due to low performance on the associative inference test (12.5% correct), which provided an insufficient number of detail/source trials to compare before and after successful inference; thus our final older adult sample consisted of 24 participants (age range: 65-85; mean age = 73.8, SD = 6.67; 16 female). The older adults were also screened with a neuropsychological battery prior to participating in the study and were considered cognitively healthy (Mini-Mental Status Examination scores of 25-30, $M = 29.54$, $SD = 0.66$).

The first comparison group of twenty-nine young adults, tested at a 24-hour study-test delay, were recruited via advertisements at Boston University and Harvard University. All had normal vision and no history of neurological impairment. They gave informed consent and were treated in accordance with guidelines approved by the ethics committee at Harvard University, and received either course credit or payment for completing the study. Three participants were excluded from all analyses due to extremely high performance on the associative inference trials (above 91% correct), which provided an insufficient number of triads where the participants correctly recalled the directly learned associations *and* incorrectly inferred the relationship between the 'A' and 'C' item, thereby precluding any meaningful comparisons of successful to unsuccessful inference both before and after inferential retrieval. One participant was excluded due to low performance on the associative inference trials (29.17%), which provided an insufficient number of successful inference triads both before and after inferential retrieval. Lastly, one participant was excluded due to technical difficulties during the second session (i.e., unplugged the computer prior to completing the task). Thus, our final young adult sample, tested at a 24-hour delay, consisted of 24 usable participants (age range: 18-24, mean age = 19.3, SD = 1.46; 10 female). Older adults had on average completed more years of education ($M = 16.41$, $SD = 2.02$) than younger adults ($M = 13.36$, $SD = 1.32$).

The second comparison group of twenty-five young adults, tested at a 48-hour study-test delay, was reported in Experiment 2 of a previous paper (age range: 18-24; mean age = 20, SD = 1.93; 14 female; Carpenter & Schacter, 2017). One younger adult was excluded from all analyses for having prior experience with several of the task stimuli; thus, our final younger adult sample consisted of 24 participants. Older adults had on average completed more years of education ($M = 16.41$, $SD = 2.02$) than younger adults ($M = 14.16$, $SD = 1.91$). Data from both younger adult groups and the older adult group were collected by the same experimenter (A.C. Carpenter), utilizing the identical stimuli, experimental design, and instructions to participants.

Stimuli and Design

The current experiment required two experimental sessions separated by a 24-hour (older adults and younger adults) or 48-hour (younger adults) delay that were executed on an Apple desktop computer using PsychoPy2 (v1.80.03). During the first session, participants viewed 72 still color images depicting everyday life events (e.g., walking to work). Color images of common objects (e.g., toy truck) and individuals were superimposed on outdoor and indoor scenes. Overlapping AB and BC pairs (24 AB pairs, 24 BC pairs – 24 total ABC triads) were constructed such that two individuals ('A' and 'C') shared an association with an overlapping object ('B;' i.e., one ABC triad). Twenty-four non-overlapping XY pairs were constructed of unique individual – object pairs that did not share an overlapping association with other pairings. Each image was randomly presented for 10 seconds within each encoding block (i.e., AB encoding: 24 AB, 12 XY and BC encoding: 24 BC, 12 XY). Participants were instructed to learn the direct associations (i.e., AB, BC), the indirect associations (i.e., AC), and the contextual information presented; participants were aware that their memory for this information would be tested during the second session.

In the second session, participants completed two sets of detail and source monitoring questions (10 questions per ABC triad), which were separated by a test for the directly learned and associative inference trials. Detail questions were directly related to background details that were present but contradictory in the AB and BC scenes (see Figure 1). A cutout of the cue individual (i.e., either ‘A’ or ‘C’) was presented to the right of each detail question in order to indicate which scene the question was referring to (Figure 1). Critically, the detail questions did not reference the overlapping ‘B’ item. For each detail question, participants were given three options: the correct item, a misinformation item, and an unrelated foil item. The misinformation item consisted of contradictory information from the overlapping image in the triad (e.g., if the detail question were related to the AB image, the misinformation item would be a contradicting detail from the BC image, such as a brown couch when a white couch had appeared in the AB image). Foil items were details that were not presented in either of the overlapping images (e.g., grey couch). Following each detail question, participants indicated where they remember seeing this contextual detail (i.e., the source of the information; Figure 1). Participants were given four possible answer choices: 1) the first set of images – AB, 2) the second set of images – BC, 3) both sets of images, or 4) unsure. Immediately following participants’ source monitoring response, they were asked to rate their confidence in their response on a scale from 1 to 4 (1 = very unsure, 4 = very sure). The presentation order of each detail/source question was randomized for each participant and the questions were self-paced.

Following the first half of the detail and source questions, participants were tested on the directly learned (AB and BC) and associative inference trials (AC). During each directly learned trial, a single cue individual (e.g., an ‘A’ or ‘C’ individual) was presented at the top of the screen and two choice objects were presented at the bottom of the screen (e.g., two ‘B’ objects from different ABC triads; Figure 1). On the associative inference trials, a cue individual (‘A’) was presented along with two individuals at the bottom of the screen (i.e., the correct ‘C’ individual from the currently cued ABC triad and a lure ‘C’ individual from another triad). Participants were instructed on associative inference trials that the association between the cue (‘A’) and the correct choice (‘C’) was indirect, mediated through an object (‘B’) that shared an association with both the cue and the correct choice during encoding. Participants were additionally able to respond ‘neither’ when they believed that neither of the two answer choices were in any way related to the cue individual (i.e., chance of 33%). The presentation order of the trials was randomized with the only constraint being that associative inference trials were shown before their corresponding AB and BC directly learned trials. Doing so ensures that participants were not able to form an association between ‘A’ and ‘C’ individuals during test based solely on the co-occurrence of answer options presented on the corresponding directly learned trials. Following each of the directly learned and associative inference trials, participants rated their confidence on a scale from 1 to 4 (1 = very unsure, 4 = very sure).

Results

We consider first the results based on comparing old adults and young adults who were matched on study-test delay, and then turn to the results based on comparing old and young adults matched on level of associative inference performance and overall source memory errors by using different study-test delays.

Matched Study-Test Delay

Directly Learned and Associative Inference Trials—We evaluated *overall* accuracy on directly learned and associative inference trials for younger adults tested at a 24-hour delay and older adults. Younger adults showed higher levels of accuracy on directly learned trials (M_{direct} = 0.81, SE = 0.02) compared to older adults (M_{direct} = 0.59, SE = 0.02; $t(46) = 7.12$, $p < .001$, mean difference = 0.22, 95% confidence interval (CI) = [0.16, 0.28], d = 2.06). Additionally, younger adults' showed higher levels of accuracy on associative inference trials ($M_{associative\ inference}$ = 0.71, SE = 0.03) compared to older adults ($M_{associative\ inference}$ = 0.61, SE = 0.04; $t(46) = 2.34$, $p = .024$., mean difference = 0.11, 95% confidence interval (CI) = [0.02, 0.20], d = .68; see Table 1).

We conducted a 2 (target: directly learned vs. associative inference) X 2 (age: younger vs. older adults) repeated measures analysis of variance (ANOVA) to evaluate participants' reaction times for directly learned and associative inference trials for older and younger adults. Results revealed a main effect of target, $F(1,46) = 66.49$, $p < .001$, $\eta_p^2 = .59$, a main effect of age, $F(1,46) = 131.66$, $p < .001$, $\eta_p^2 = .74$, and a significant target by age interaction, $F(1,46) = 8.85$, $p = .005$, $\eta_p^2 = .16$. Consistent with previous research (Carpenter & Schacter, 2017), we found significantly longer reaction times on associative inference trials compared to directly learned trials for *both* younger ($M_{associative\ inference}$ = 5005 msec, SE = 263; M_{direct} = 3107 msec, SE = 140; $t(23) = 9.84$, $p < .001$, mean difference = 1898, 95% CI = [1499, 2297], d = 2.01) and older adults ($M_{associative\ inference}$ = 11933 msec, SE = 751; M_{direct} = 7855 msec, SE = 365; $t(23) = 5.77$, $p < .001$, mean difference = 4078, 95% CI = [2615, 5540], d = 1.18; see Table 1), suggesting an additional recombination-related retrieval mechanism for inferential versus direct retrieval.

Further, we conducted an identical repeated measures ANOVA to evaluate confidence ratings for directly learned and associative inference trials for older and younger adults. Results revealed a main effect of target, $F(1,46) = 56.42$, $p < .001$, $\eta_p^2 = .55$, a main effect of age, $F(1,46) = 28$, $p < .001$, $\eta_p^2 = .38$, but no target by age interaction, $F(1,46) < 1$, $p > .250$, $\eta_p^2 = .006$. Consistent with previous research (Carpenter & Schacter, 2017), results showed that participants were significantly more confident in their responses on directly learned compared to associative inference trials for *both* younger (M_{direct} = 3.35, SE = .05; $M_{associative\ inference}$ = 2.96, SE = .07; $t(23) = 7.77$, $p < .001$, mean difference = 0.40, 95% CI = [0.29, 0.50], d = 1.59) and older adults (M_{direct} = 2.68, SE = .12; $M_{associative\ inference}$ = 2.34, SE = .11; $t(23) = 4.08$, $p < .001$, mean difference = 0.34, 95% CI = [0.17, 0.52], d = .83; see Table 1).

False Memory—False memories were defined as detail questions for which the participant both chose the misinformation detail *and* attributed the misinformation detail incorrectly to either the currently cued image or both images in the triad. To assess the effects of recombination mechanisms at retrieval on subsequent source memory errors for younger and older adults, we examined source memory errors for the detail and source monitoring questions with a 2 (time: before vs. after inference retrieval) X 2 (inference: correct vs. incorrect inference) X 2 (age: younger vs. older adults) repeated measures ANOVA. Importantly, only trials for which participants correctly remembered the directly learned associations were included in all subsequent analyses. Critically, results revealed a significant three-way time by inference by age interaction, $F(1,46) = 4.05$, $p = .050$, $\eta_p^2 = .08$ (see Figure 2).

In order to characterize the three-way interaction effects we conducted two 2 (time: before vs. after inference) X 2 (inference: correct vs. incorrect inference) repeated measures ANOVAs for younger and older adults separately (see Table 2 for raw trial numbers). Results from younger adults revealed a significant time by inference interaction, $F(1,23) = 4.85$, $p = .038$, $\eta_p^2 = .17$. Younger adults falsely attributed more details to the overlapping event after successful inference retrieval ($M_{after} = 0.31$, SE = 0.02) than before successful inference retrieval ($M_{before} = 0.25$, SE = 0.01; $t(23) = 2.42$, $p = .024$, mean difference = 0.06, 95% CI = [0.01, 0.11], $d = .49$). Further, younger adults did not falsely attribute more details to the overlapping event after unsuccessful inference retrieval ($M_{after} = 0.22$, SE = 0.02) than before unsuccessful inference retrieval ($M_{before} = 0.25$, SE = 0.02; $t(23) < 1$, $p > .250$, mean difference = −0.03, 95% CI = [-0.10, 0.04], $d = .20$). Younger adults did not falsely attribute more details to the overlapping event before successful inference retrieval ($M_{correct} = 0.25$, SE = 0.01) than before unsuccessful inference retrieval ($M_{incorrect} = 0.25$, SE = 0.02; $t(23) < 1$, $p > .250$, mean difference = 0.002, 95% CI = [-0.06, 0.05], $d = .02$). Critically, younger adults falsely attributed more details to the overlapping event after successful inference retrieval ($M_{correct} = 0.31$, SE = 0.02) than after unsuccessful inference retrieval ($M_{incorrect} = 0.22$, SE = 0.02; $t(23) = 2.74$, $p = .012$, mean difference = 0.09, 95% CI = [0.02, 0.15], $d = .56$), suggesting that recombination during retrieval required for successful inference is linked to source memory errors.

Results from older adults revealed no main effect of time, $F(1,23) = 1.73$, $p = .202$, $\eta_p^2 = .07$, no main effect of inference, $F(1,23) < 1$, $p > .250$, $\eta_p^2 = .004$, and importantly no time by inference interaction, $F(1,23) < 1$, $p > .250$, $\eta_p^2 = .006$ (see Table 3 for means). However, when all detail/source questions were included (i.e., not conditionalized on successful/unsuccessful inference or participants' performance on directly learned trials), older adults showed significantly higher rates of source memory error ($M_{total} = 0.29$, SE = 0.01) compared to younger adults ($M_{total} = 0.25$, SE = 0.01; $t(46) = 2.21$, $p = .032$, mean difference = 0.03, 95% CI = [0.003, 0.07], $d = .64$).

True Memory—True memories were defined as detail questions for which the participant both chose the correct detail *and* attributed the source of their memory correctly to the currently cued image. To assess the effects of our key manipulation on subsequent true memory for younger and older adults, we examined true memory for the detail and source monitoring questions with a 2 (time: before vs. after inference retrieval) X 2 (inference: correct vs. incorrect inference) X 2 (age: younger vs. older adults) repeated measures ANOVA. Results revealed a main effect of age, $F(1,46) = 6.21$, $p = .016$, $\eta_p^2 = .12$, with more true memories for younger ($M_{younger\ adults} = 0.26$, SE = 0.02) than older adults ($M_{older\ adults} = 0.18$, SE = 0.03); no other significant main effects or interactions were found, all $Fs(1,46) < 1$, $ps > .250$, $\eta_p^2 < .02$ (see Table 3 for means).

Foil Memory—To assess whether critical patterns of source memory errors are specific to related items from previously studied episodes, we examined foil memories, which were defined as detail questions for which participants chose the unrelated foil option (e.g., grey couch) and attributed the information to either the currently cued image or both images in the triad. We conducted a 2 (time: before vs. after inference retrieval) X 2 (inference: correct vs. incorrect inference) X 2 (age: younger vs. older adults) repeated measures ANOVA to evaluate participants' foil memory scores. Results revealed a main effect of time, $F(1,46) = 7.13$, $p = .010$, $\eta_p^2 = .13$, with more foil memories after ($M_{after} = 0.18$, SE = 0.01) compared to before ($M_{before} = 0.15$, SE = 0.01) the test of directly learned and associative inference trials. Critically, after the test of directly learned and associative inference trials there was no significant difference in the proportion of foil memories following successful ($M_{correct} = 0.19$, SE = 0.02) compared to unsuccessful inference ($M_{incorrect} = 0.17$, SE = 0.01; $t(47) = 1.24$, $p = .22$, mean difference = 0.02, 95% CI = [-0.01, 0.05], $d = .18$). There was a trend toward a main effect of age, $F(1,46) = 3.86$, $p = .06$, $\eta_p^2 = .08$, with marginally more foil memories for younger adults ($M_{younger\ adults} = 0.18$, SE = 0.01) than older adults ($M_{older\ adults} = 0.14$, SE = 0.02); no other significant main effects or interactions were found, all $Fs(1,46) < 1.64$, $ps > .20$, $\eta_p^2 < .04$ (see Table 3 for means).

Matched Performance for Associative Inference and Source Memory Errors

Directly Learned and Associative Inference Trials—We first consider *overall* accuracy on directly learned and associative inference trials for younger adults tested at a 48-hour delay and older adults at the 24-hour delay. Younger adults showed higher levels of accuracy on directly learned trials ($M_{direct} = 0.69$, SE = 0.03) compared to older adults ($M_{direct} = 0.59$, SE = 0.02; $t(46) = 2.63$, $p = .012$, mean difference = 0.09, 95% confidence interval (CI) = [0.02, 0.17], $d = .76$)[1]. Critically, younger adults' accuracy on associative inference trials ($M_{associative\ inference} = 0.64$, SE = 0.03) did not significantly differ from older adults' accuracy ($M_{associative\ inference} = 0.61$, SE = 0.04; $t(46) < 1$, $p > .250$., mean difference = 0.03, 95% confidence interval (CI) = [-0.07, 0.13], $d = .18$; see Table 1).

We conducted an identical repeated measures ANOVA to evaluate participants' reaction times for directly learned and associative inference trials for older and younger adults. Results revealed a main effect of target, $F(1,46) = 55.85$, $p < .001$, $\eta_p^2 = .55$, a main effect of age, $F(1,46) = 158.30$, $p < .001$, $\eta_p^2 = .78$, and a significant target by age interaction, $F(1,46) = 14.12$, $p < .001$, $\eta_p^2 = .24$. As in the matched study-test delay analysis, we found significantly longer reaction times on associative inference trials compared to directly learned trials for younger adults ($M_{associative\ inference} = 4401$ msec, SE = 185; $M_{direct} = 3052$ msec, SE = 129; $t(23) = 5.66$, $p < .001$, mean difference = 1349, 95% CI = [989, 1709], $d = 1.62$; analysis for older adults reported above; see Table 1), suggesting an additional recombination-related retrieval mechanism for inferential versus direct retrieval.

[1]Younger adults' performance on directly learned trials ($M_{direct} = 0.69$, SE = 0.03) was marginally higher compared to associative inference trials ($M_{associative\ inference} = 0.64$, SE = 0.03; $t(23) = 2.10$, $p = .047$, mean difference = 0.05, 95% confidence interval (CI) = [0.007, 0.10], $d = .43$) and older adults' performance on directly learned trials ($M_{direct} = 0.59$, SE = 0.02) was not significantly different from their performance on associative inference trials ($M_{associative\ inference} = 0.61$, SE = 0.04; $t(23) < 1$, $p > .25$, mean difference = −0.01, 95% confidence interval (CI) = [-0.08, 0.05], $d = .09$).

Further, we conducted an identical repeated measures ANOVA to evaluate confidence ratings for directly learned and associative inference trials for older and younger adults. Results revealed a main effect of target, $F(1,46) = 47.06$, $p < .001$, $\eta_p^2 = .51$, a main effect of age, $F(1,46) = 15.11$, $p < .001$, $\eta_p^2 = .25$, but no target by age interaction, $F(1,46) < 1$, $p > .250$, $\eta_p^2 = .004$. Just as in the matched study-test delay analysis, results revealed that young adults were significantly more confident in their responses on directly learned compared to associative inference trials for both younger ($M_{direct} = 3.22$, SE = .09; $M_{associative\ inference} = 2.83$, SE = .08; $t(23) = 5.67$, $p < .001$, mean difference = 0.39, 95% CI = [0.25, 0.53], $d = 1.18$), as were older adults (analysis reported above; see Table 1).

False Memory—To assess the effects of recombination mechanisms at retrieval on subsequent source memory errors for younger and older adults, we examined source memory errors for the detail and source monitoring questions with a 2 (time: before vs. after inference retrieval) X 2 (inference: correct vs. incorrect inference) X 2 (age: younger vs. older adults) repeated measures ANOVA comparing younger adults at a 48-hour delay and older adults at a 24-hour delay. Replicating the matched study-test delay analysis, results revealed a significant three-way time by inference by age interaction, $F(1,46) = 5.51$, $p = .023$, $\eta_p^2 = .11$ (see Figure 2).

In order to characterize the three-way interaction effects we conducted an additional (time: before vs. after inference) X 2 (inference: correct vs. incorrect inference) repeated measures ANOVA for our second younger adult group (see Table 2 for raw trial numbers). Results from younger adults revealed a significant time by inference interaction $F(1,23) = 7.40$, $p = .012$, $\eta_p^2 = .24$. As previously reported in Experiment 2 of Carpenter and Schacter (2017), younger adults falsely attributed more details to the overlapping event after successful inference retrieval ($M_{after} = 0.28$, SE = 0.02) than before successful inference retrieval ($M_{before} = 0.22$, SE = 0.02; $t(23) = 2.48$, $p = .021$, mean difference = 0.06, 95% CI = [0.01, 0.11], $d = .51$). Further, participants did not falsely attribute more details to the overlapping event after unsuccessful inference retrieval ($M_{after} = 0.22$, SE = 0.02) than before unsuccessful inference retrieval ($M_{before} = 0.25$, SE = 0.03; $t(23) = -1.022$, $p > .250$, mean difference = -0.03, 95% CI = [-0.10, 0.03], $d = .21$). Participants did not falsely attribute more details to the overlapping event before successful inference retrieval ($M_{correct} = 0.22$, SE = 0.02) than before unsuccessful inference retrieval ($M_{incorrect} = 0.25$, SE = 0.03; $t(23) = 1.40$, $p = .175$, mean difference = 0.03, 95% CI = [−0.02, 0.08], $d = .29$). Critically, young adults falsely attributed more details to the overlapping event after successful inference retrieval ($M_{correct} = 0.28$, SE = 0.02) than after unsuccessful inference retrieval ($M_{incorrect} = 0.22$, SE = 0.02; $t(23) = 2.56$, $p = .018$, mean difference = 0.06, 95% CI = [0.01, 0.11], $d = .52$), suggesting that recombination during retrieval required for successful inference is linked to source memory errors.

Results from the separate older adult ANOVA are reported above in the previous comparison to our younger adult group tested under a matched study-test delay period. Importantly, when younger adults tested at a 48-hour delay were compared to older adults tested at a 24-hour delay, and all detail/source questions were included (i.e., not conditionalized on successful/ unsuccessful inference or participants' performance on directly learned trials) there was no significant difference in the overall levels of source memory error for younger

(M_{total} = 0.29, SE = 0.007) compared to older adults (M_{total} = 0.29, SE = 0.01; $t(46) < 1$, $p > .250$, mean difference = 0.004, 95% CI = [-0.23, 0.03], $d = .09$). Thus, when groups were matched on inference accuracy and overall rates of source memory errors, younger adults showed an increase in false memories following successful inference, whereas older adults did not.

True Memory

As in the analysis of the matched study-test delay data, we also examined true memory for the detail and source monitoring questions with a 2 (time: before vs. after inference retrieval) X 2 (inference: correct vs. incorrect inference) X 2 (age: younger vs. older adults) repeated measures ANOVA. Results revealed a significant main effect of time $F(1,46) = 5.85$, $p = .020$, $\eta_p^2 = .11$, with more correct memories after (M_{after} = 0.20, SE = 0.02) than before (M_{before} = 0.17, SE = 0.02) inferential retrieval; no other significant main effects, age differences or interactions were found, all Fs(1,46) < 2.20, ps > .15, $\eta_p^2 < .045$ (see Table 3 for means). Notably, after the test of directly learned and associative inference trials there was no significant difference in the proportion of true memories following successful ($M_{correct}$ = 0.21, SE = 0.02) compared to unsuccessful inference ($M_{incorrect}$ = 0.20, SE = 0.02; $t(47) < 1$, $p > .250$, mean difference = -0.009, 95% CI = [-0.04, 0.02], $d = .09$).

Foil Memory—We conducted a 2 (time: before vs. after inference retrieval) X 2 (inference: correct vs. incorrect inference) X 2 (age: younger vs. older adults) repeated measures ANOVA to evaluate participants' foil memory scores. Results revealed a main effect of age, $F(1,46) = 5.22$, $p = .027$, $\eta_p^2 = .10$, with more foil memories for younger (M = 0.20, SE = 0.02) than older adults (M = 0.14, SE = 0.02); no other significant main effects or interactions were found, all Fs(1,46) < 2.30, ps > .14, $\eta_p^2 < .047$ (see Table 3 for means).

Discussion

The experiment reported here provides novel evidence of age-related changes in the consequences of successful associative inference for subsequent false memories. When older adults were able to successfully infer the relationship between two elements from related episodes that had never been directly paired (i.e., 'A' and 'C'), they did not exhibit the same increase in false memories for contextual details from the two related episodes following successful associative inference that we previously reported in younger adults (Carpenter & Schacter, 2017). This observation is striking because in many situations, older adults are *more* prone to source misattributions and related false memories than are younger adults (for review, see Devitt & Schacter, 2016).

When we compared results from the older adult group reported here (i.e., 24-hour study-test delay) to either a young adult group tested under identical experimental conditions or to a young adult group tested at a 48-hour study-test delay who were equated on associative inference performance and overall source memory errors, we observed the identical pattern of results: young adults showed an increase in false memories only following successful inference whereas older adults did not. It should also be noted that when we compared the current group of older adults to the group of younger adults tested under identical experimental conditions we did find the typical age-related increase in *overall* source memory errors; critically, this increase was independent of both whether the detail/source monitoring test was given before or after the test of directly learned and associative inference trials and whether inference was successful or unsuccessful. Importantly, we also compared the older adult group at a 24-hour delay to the younger adult group at a 48-hour delay because these two groups were equated both on associative inference accuracy and overall proportions of source memory errors. Thus, the age-related difference in false memory following successful inference reported here cannot be attributable to age differences in associative inference performance or overall age-related increases in source memory errors. Further, there were no time × inference × age interactions for true memories or foil memories in either of the two age-related comparisons reported here. Thus, the age-related differences reported here are specific to reductions in source memory errors for older compared with younger adults following successful associative inference (for other evidence concerning associative inference in older adults, see Ryan, Moses, & Villate, 2009).

We have previously suggested that the increase in source memory errors following successful inferential retrieval for younger adults depends on both cross-episode binding (e.g., Bridge & Voss, 2014a, 2014b) and retrieval-related recombination mechanisms (e.g., Carpenter & Schacter, 2017; Hupbach, Gomez, Hardt, & Nadel, 2007; St. Jacques & Schacter, 2013). We have argued that cross-episode binding in our paradigm occurs most extensively for episodes that result in successful, as opposed to unsuccessful, associative inference (Carpenter & Schacter, 2017). That is, when younger adults successfully infer the relationship between ‘A’ and ‘C,’ they may bind details from the two episodes, such that details from one episode (AB) migrate to and become incorporated in the overlapping (BC) episode. In addition, flexible recombination mechanisms operating during the associative inference test allow young adults to reactivate and recombine elements of the overlapping AB and BC relationships (along with their corresponding contextual details) in order to encode the novel inference between the previously unrelated ‘A’ and ‘C’ items. Thus, we suggest that successful inference involves a retrieval-related recombination process that results in increased source memory errors in younger adults (as discussed at length in Carpenter & Schacter, 2017). Successful associative inference can also be achieved via an *integrative encoding* mechanism (e.g., Shohamy & Wagner, 2008), but this mechanism cannot account for the selective increase in false memories only *after* successful inferential retrieval). Indeed, in the current experiment we observed significantly longer reaction times on associative inference trials than on directly learned trials for *both* younger and older adults, which is consistent with previous research utilizing a similar associative inference paradigm (Carpenter & Schacter, 2017; Zeithamova & Preston, 2010), suggesting that there may be an additional recombination-related retrieval mechanism necessary for inferential compared to direct retrieval.

In contrast to this account of young adult performance, the current results suggest that when older adults reactivate overlapping AB and BC events while successfully inferring the relationship between ‘A’ and ‘C’ items during the associative inference test, the corresponding event details (e.g., AB) are less fully bound to the overlapping event context (e.g., BC). Thus, older adults make relatively fewer source memory errors following successful inference compared to younger adults. Based on previous research showing reduced retrieval of episodic details in older compared to younger adults (e.g., Addis, Wong,

& Schacter, 2008; Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002), in concert with related research highlighting disproportionate age-related declines in remembering specific contextual and associative information (Old & Naveh-Benjamin, 2008; Smyth & Naveh-Benjamin, 2016), we suggest that when older adults successfully infer the relationship between items ‘A’ and ‘C’ they reactivate the episodic or contextual details of the AB and BC events less richly than do younger adults. Thus, when older adults make the correct inference across the two overlapping (AB and BC) episodes, they bind fewer contextual details across episodes, producing fewer source misattributions.

There are at least two possibilities as to why older adults may less richly reactivate the overlapping contextual details when making a successful inference judgment. Older adults could 1) fail to retrieve related episodic or contextual details that are available in memory or 2) fail to initially encode contextual details sufficiently to facilitate their subsequent recall during successful inferential retrieval. Future research should attempt to distinguish between these two possibilities by manipulating how older adults encode or retrieve the contextual details of overlapping events.

We conclude by noting a couple of cautionary items. First, our theoretical account of the age difference in inference-dependent false memories observed here is based on a single experiment, and thus must remain tentative pending replication of our results. Second, although associative inference performance did not differ significantly between younger adults tested at a 48-hour delay and older adults tested at a 24-hour delay, there was a significant age-related decline on directly learned trials. Critically, our key false memory results were conditionalized on correct directly learned trials, which mitigates this concern. Nonetheless, future research should attempt to replicate the current results under conditions that elicit similar levels of performance on both associative inference and directly learned trials for younger and older adults.

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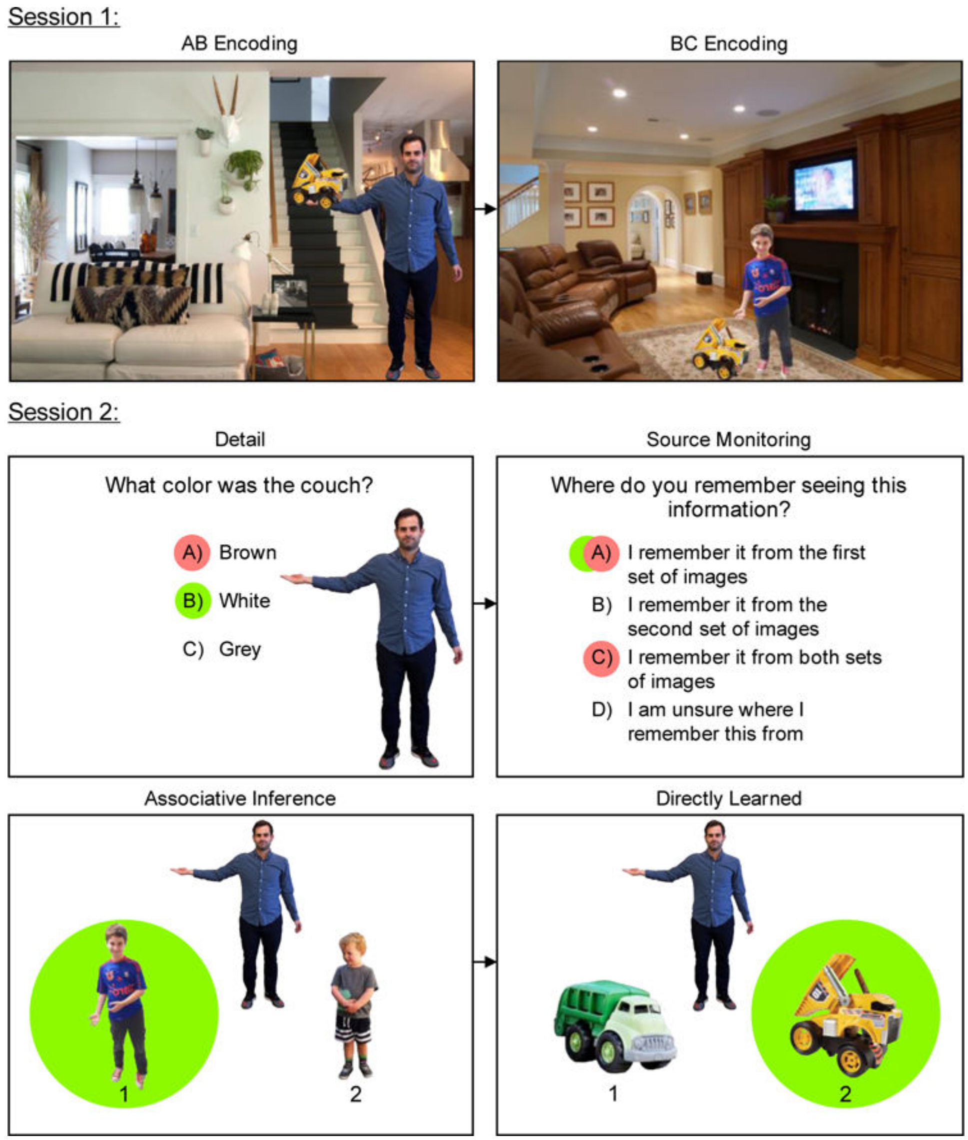

Figure 1. Overview of Experimental Procedure

Illustration of materials, stimuli, and test displays. The Session 1 section shows one example of an AB image in which the man is item ‘A’ and the toy truck is item ‘B’ and the corresponding BC image in which the boy is item ‘C.’ The Session 2 section shows one example of a detail and source monitoring question linked to the example AB image. For each detail question, participants saw a cutout of the ‘A’ or ‘C’ individual presented to the right of the question in order to indicate to which event the question referred. False memories occurred when participants chose both the misinformation detail (e.g., brown couch) during the detail question and attributed the misinformation detail incorrectly to either the original event or both events – as indicated by the red (dark) circles. True memories occurred when participants both chose the correct detail during the detail question (e.g., white couch) and attributed the correct detail correctly to the original event – as indicated by the green (light) circles. Other example detail questions for this ABC triad included: Where were the stairs located?; What color were the walls in the room?; What was this individual sitting/standing on?; What was hanging on the wall directly behind this individual?; etc. Importantly, all of these questions relate to two contradictory details from images AB and BC (e.g., stairs directly behind vs. to the far left; yellow vs. white walls; wood floors vs. carpet; potted plants vs. picture frames; etc.). For the directly learned and associative inference questions, the green (light) circles indicate the correct answer. Participants saw these questions without the red (dark) and green (light) circles. Figure 1 is reprinted from Carpenter, A.C. & Schacter, D.L. (2017). Flexible retrieval: When true inferences produce false memories. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 43(3), 335-349. Reprinted with permission of the American Psychological Association.

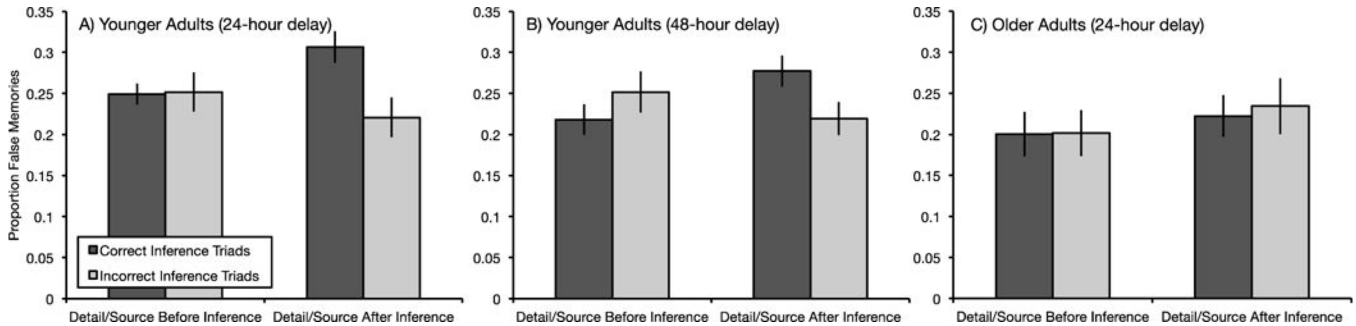

Figure 2.

Proportion of false memories for (A) younger adults at a 24-hour study-test delay, (B) younger adults at a 48-hour study-test delay (C) and older adults at a 24-hour study-test delay. Performance on detail and source monitoring questions was examined both before and after either successful or unsuccessful inference. Importantly, only trials for which participants responded correctly to directly learned trials were included in this analysis. Results revealed a significant three-way time by inference by age interaction for both of our age-related comparisons of interest. Subsequent t-tests confirm that false memories selectively increased for younger adults only following successful associative inference. No differences in false memories were found for older adults. Error bars represent ± 1 SEM.

Table 1

Average accuracy, reaction time (msec), and confidence ratings (SE) for directly learned and associative inference trials for younger (24-hour and 48-hour study-test delay) and older adults (24-hour study-test delay).

Accuracy	***Directly Learned***	***Associative Inference***
Younger Adults (24-hour)	0.81 (0.02)	0.71 (0.03)
Younger Adults (48-hour)	0.69 (0.03)	0.64 (0.03)
Older Adults (24-hour)	0.58 (0.02)	0.61 (0.04)
Reaction Time (RT)	*Directly Learned*	*Associative Inference*
Younger Adults (24-hour)	3107 (140)	5005 (293)
Younger Adults (48-hour)	3052 (129)	4401 (185)
Older Adults (24-hour)	7855 (365)	11933 (751)
Confidence	*Directly Learned*	*Associative Inference*
Younger Adults (24-hour)	3.35 (0.05)	2.96 (0.07)
Younger Adults (48-hour)	3.22 (0.09)	2.83 (0.08)
Older Adults (24-hour)	2.68 (0.12)	2.34 (0.11)

Table 2

Average raw number of trials from the detail and source monitoring questions that contributed to the proportion of false memories for younger (24-hour and 48-hour study-test delay) and older adults (24-hour study-test delay); reaction time data for trials that contributed to the proportion of false memories (msec); and participants' confidence ratings (1=very unsure, 4=very sure) for trials that contributed to the proportion of false memories. Statistics were computed based on un-weighted individual subject means, whereas the raw trial numbers here are averaged across participants. Performance on detail and source monitoring questions was examined both before and after either successful or unsuccessful inference. Importantly, only trials for which participants responded correctly on directly learned trials were included.

	False Memories	**Before Associative Inference**		**After Associative Inference**	
		Unsuccessful Inference	***Successful Inference***	***Unsuccessful Inference***	***Successful Inference***
Younger Adults	*Raw False Memory Trial Number (SE)*	4.04 (0.57)	18.04 (1.71)	4.83 (0.83)	17.38 (1.86)
(24-hour)	*Raw Total Trial Number (SE)*	16.25 (1.89)	70.42 (4.72)	20.83 (2.33)	57.92 (5.25)
	RT msec (SE)	7659 (717)	7892 (529)	8492 (720)	6634 (375)
	Confidence (SE)	2.18 (0.15)	2.45(0.11)	2.21 (0.15)	2.50 (0.13)
Younger Adults	*Raw False Memory Trial Number (SE)*	6.79 (1.10)	13.79 (1.87)	5.25 (0.92)	15.71 (1.65)
(48-hour)	*Raw Total Trial Number (SE)*	28.33 (3.23)	60.16 (5.06)	23 (2.65)	55.30 (4.52)
	RT msec (SE)	6497 (1193)	5513 (685)	4693 (548)	5847 (694)
	Confidence (SE)	2.38 (0.20)	2.34 (0.17)	2.31 (0.15)	2.28 (0.14)
Older Adults	*Raw False Memory Trial Number (SE)*	4.88 (1.03)	8.83 (1.38)	5.88 (1.06)	11.29 (1.69)
(24-hour)	*Raw Total Trial Number (SE)*	24.83 (3.07)	46.21 (4.69)	25.79 (3.66)	46 (3.90)
	RT msec (SE)	14277 (1105)	15510 (1278)	14150 (1603)	12798 (1226)
	Confidence (SE)	2.15 (0.11)	2.19 (0.10)	2.15 (0.15)	2.20 (0.17)

Table 3

Proportion of false, true and foil memories (SE) for younger (24-hour and 48-hour study-test delay) and older adults (24-hour study-test delay). Participants were given three response options (i.e., correct, misinformation, foil) for the detail questions and four response options for the source monitoring questions (i.e., first set of images, second set of images, both sets of images, unsure). False memories were defined as detail questions for which the participant both chose the misinformation detail *and* attributed the misinformation detail incorrectly to either the currently cued image or both images in the triad. True memories were defined as detail questions for which the participant both chose the correct detail *and* attributed the source of their memory correctly to the currently cued image. Foil memories were defined as detail questions for which participants chose the unrelated foil option *and* attributed the information to either the currently cued image or both images in the triad. Thus, these proportions represent only a subset of all possible detail and source monitoring response combinations.

False Memories	**Before Associative Inference**		**After Associative Inference**	
	Unsuccessful Inference	***Successful Inference***	***Unsuccessful Inference***	***Successful Inference***
Younger Adults (24-hour)	0.25 (0.02)	0.25 (0.01)	0.22 (0.02)	0.31 (0.02)
Younger Adults (48-hour)	0.25 (0.03)	0.22 (0.02)	0.22 (0.02)	0.28 (0.02)
Older Adults (24-hour)	0.20 (0.03)	0.20 (0.03)	0.23 (0.03)	0.22 (0.03)
True Memories	Before Associative Inference		After Associative Inference	
	Unsuccessful Inference	*Successful Inference*	*Unsuccessful Inference*	*Successful Inference*
Younger Adults (24-hour)	0.27 (0.04)	0.27 (0.02)	0.28 (0.03)	0.26 (0.02)
Younger Adults (48-hour)	0.16 (0.03)	0.18 (0.03)	0.20 (0.03)	0.21 (0.03)
Older Adults (24-hour)	0.18 (0.04)	0.16 (0.02)	0.20 (0.03)	0.20 (0.03)
Foil Memories	Before Associative Inference		After Associative Inference	
	Unsuccessful Inference	*Successful Inference*	*Unsuccessful Inference*	*Successful Inference*
Younger Adults (24-hour)	0.15 (0.02)	0.17 (0.01)	0.22 (0.02)	0.19 (0.02)
Younger Adults (48-hour)	0.21 (0.03)	0.21 (0.02)	0.21 (0.02)	0.17 (0.02)
Older Adults (24-hour)	0.13 (0.03)	0.12 (0.02)	0.15 (0.03)	0.14 (0.02)