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The role of schematic support in age-related associative deficits in short-term and long-term memory

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ABSTRACT

Older, relative to younger adults, exhibit an associative memory deficit in short-term and long-term memory, characterized by difficulty in binding distinct components to form associations, while item memory remains largely intact. Reduced performance emerges mostly due to high false alarm rates in older adults' associative memory. One factor that could increase older adult false alarm rates during associative recognition memory tests is a decreased use of recollection processes that allow the rejection of recombined components from the study phase. The current experiments assessed the degree to which an increase in the use of semantic memory (schematic) support, by changing the patterns of support from study to test, can help older adults reduce their associative false alarms using recollection. In two experiments, face–name pairs were presented to younger and older adults. During a continuous recognition task assessing memory performance at short-term and long-term memory retention intervals, younger and older adults were tested on individual faces, names, and face–name pairs that either remained intact or were recombined within the same (e.g., old-face, old-name) or between two different age categories (e.g., old-face, young-name). In Experiment 2, we also collected "remember–know" judgments after responses to recognition test events. In both experiments, the results indicated benefits to older adults' associative memory when changes in schematic support occurred from study to test at long-term but not short-term memory retention intervals. The results of Experiment 2 indicate that these increases in performance were mediated by the availability of recollection processes during retrieval.

Introduction

Senescent decline in the ability to encode, maintain, and retrieve information is a common occurrence for aging populations. For instance, age-related declines in episodic memory processes are well documented (for reviews see Craik & Bialystok, 2006; Old & Naveh-Benjamin, 2008; Zacks, Hasher, & Li, 2000) despite relatively preserved semantic memory (Kausler & Puckett, 1980). Specifically, older adults have trouble forming associations between components within episodic memory (Chalfonte & Johnson, 1996). Providing an overall theoretical perspective to account for age-related declines in episodic memory, the associative deficit hypothesis (ADH) proposes that older compared to younger adults have difficulty encoding and retrieving associations between distinct components while memory for these components remains largely intact (Naveh-Benjamin, 2000). Evidence in support of this perspective is well documented, with a variety of studies replicating and extending the findings from Naveh-Benjamin (2000) upon examining the formation of

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associations in long-term memory (LTM) between a number of distinct components (e.g., word pairs, face–name pairs, face–scene pairs, picture pairs, person–activity pairs: Bastin & Van der Linden, 2005; Castel & Craik, 2003; Naveh-Benjamin, Guez, Kilb, & Reedy, 2004; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; for a meta-analytic review see Old & Naveh-Benjamin, 2008).

While the majority of the research examining the ADH has focused on episodic memory processes, evidence from several recent studies suggests that age-related associative (or binding) deficits are apparent even within short-term memory (STM; Borg, Leroy, Favre, Laurent, & Thomas-Anterion, 2011; Chen & Naveh-Benjamin, 2012; Cowan, Naveh-Benjamin, Kilb, & Saults, 2006; Fandakova, Sander, Werkle-Bergner, & Shing, 2014; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000). However, other studies have shown no evidence of age-related binding deficits at STM retention intervals (e.g., Brockmole, Parra, Della Sala, & Logie, 2008; Experiment 1, Brown & Brockmole, 2010; Parra, Abrahams, Logie, & Della Sala, 2009; Read, Rogers, & Wilson, 2015; Rhodes, Parra, & Logie, 2016). While the nature of age-related associative deficits within STM remains unclear, recent work suggests that the type of binding process (e.g., surface vs. contextual feature binding) and use of secondary tasks (e.g., articulatory suppression) are important factors mediating the presence or absence of age-related binding deficits (Peterson & Naveh-Benjamin, 2016).

Other recent evidence, which has shown age-related deficits during STM retention intervals, suggests that one potential explanation for age-related associative memory deficits in LTM relates to inefficient encoding mechanisms when attempting to form bound representations of distinct components within short-term memory for potential transfer into LTM. Indeed, in one recent study, younger and older adults' memory for faces, scenes, and face–scene pairs were examined across both STM and LTM retention intervals within the same experiment. Using a continuous recognition task paradigm, Chen and Naveh-Benjamin (2012) examined performance for both item and associative memory across a variety of short-term and long-term retention intervals, finding consistent evidence of an age-related associative deficit.

While recent findings of age-related deficits even across short-term retention intervals suggest the involvement of inefficient encoding mechanisms, another possibility according to the ADH is that age-related differences in retrieval processes may, in part, underlie associative memory deficits. For instance, aging may differentially impact two retrieval processes involved in recognition memory, namely, familiarity and recollection (see Spencer & Raz, 1995; Yonelinas, 2002). Recollection-based recognition, involving remembering details surrounding the context in which an item was initially encountered, has been shown to decline with age, whereas familiarity-based recognition, or knowing that an item was initially encountered in the absence of contextual details, remains largely intact (Davidson & Glisky, 2002; Jacoby, Shimizu, Velanova, & Rhodes, 2005; Kilb & Naveh-Benjamin, 2011; Light, Prull, La Voie, & Healey, 2000). Intriguingly, the notion that familiarity-based, but not recollection-based recognition processes remain intact within increasing age converges with the existing evidence that older adults, relative to younger adults, exhibit impaired memory for associations but not for the components comprising these associations (Old & Naveh-Benjamin, 2008). Consistent with this notion, the ability to recognize associations is thought to rely on recollection processes as retrieval of the item and its context is necessary, whereas familiarity processes may be sufficient for recognition of the individual components (Yonelinas, 1997, 2002).

Aside from age-related differences with respect to the specific retrieval processes used during associative memory tasks, increases in age are often accompanied by an increase in retrieval errors. Specifically, the associative memory deficit is, in part, characterized by high false alarm rates, (e.g., rather than low hit rates), during associative memory tests for older relative to younger adults (Castel & Craik, 2003; Cohn, Emrich, & Moscovitch, 2008; Kilb & Naveh-Benjamin, 2011; Old & Naveh-Benjamin, 2008). Even when provided with instructions for effective use of encoding strategies to learn items and item pairs, characteristic high false alarm rates for older relative to younger adults are present, producing an age-related associative memory deficit (Shing, Werkle-Bergner, Li, & Lindenberger, 2008). Thus, during attempts at retrieval of associative pairs, older adults tend to erroneously endorse recombined pairs (i.e., false alarm) more frequently than younger adults. Accordingly, if older adults use relatively automatic retrieval processes due to decreases in strategic processing, they may rely on familiarity-based recognition during associative memory tests. As such, one possible reason for this high false alarm rate may be due to older adults' propensity to accept associative pairs based on familiarity with the components of the pair (e.g., both components of a recombined pair appeared during the study phase) in the absence of contextual details (Fandakova, Shing, & Lindenberger, 2013).

One potential reason for older adults' increased reliance on familiarity-based rather than recollection-based recognition may be due to decreased or inefficient ambient use of strategic or elaborative processing during encoding and retrieval. Indeed, recent findings have indicated that, when explicitly instructed on how to use encoding and retrieval strategies, older adults are able to improve their associative memory performance, resulting in a decreased age-related deficit (Naveh-Benjamin, Brav, & Levy, 2007). However, even if older adults are not explicitly given a strategy to use, they may be able to take advantage of certain schematic support cues included within the design of the associative memory task. For instance, when schematic support is available based on prior domain-relevant, semantic knowledge, encoding and retrieval of that domain-relevant content is enhanced, leading to memory performance improvements (Bransford & Johnson, 1972; Craik & Bosman, 1992). Given that semantic memory processes remain relatively intact with increases in age, older adults can take advantage of schematic support cues when encoding and retrieval of episodic information is necessary (Craik & Jennings, 1992). Moreover, semantic relatedness between items within an associative pair (e.g., word pairs) reduces the age-related associative memory deficit compared to when there is no relationship between the items (Naveh-Benjamin et al., 2003). Similarly, older adults are able to access and use preexisting semantic knowledge when performing a cued-recall task involving episodic memory for products paired with market-value prices regarding whether such prices are realistic given the products (e.g., Castel, 2005; McGillivray & Castel, 2010).

In addition to aiding in cued-recall performance, one intriguing possibility is that schematic support cues may facilitate associative memory performance in older adults, potentially reducing the age-related associative memory deficit. For example, schematic support cues could be manipulated by creating conditions encouraging access to pre-existing semantic knowledge wherein item components from distinct categories that comprise associative pairs are either shown within the same item category or a different item category between study and test. In the case of ecologically relevant face–name pairs, the domain-relevant knowledge could be based on the schematic congruency between, for example, the age of the face (e.g., younger, older) and the age of the name (e.g., younger, older). With experimental stimuli involving face–name pairs that vary with respect to the age category (e.g., younger, older) of each of the individual components, a given face–name pair could effectively comprise a "match" (e.g., younger face, younger name) or "mismatch" (e.g., younger face, older name, or vice versa) with respect to the perception of the age of the face and the pre-existing schema associated with the age category to which the name belongs (e.g., a younger or older person's name).

However, a change in schematic support occurring between face–name pairs from the study phase to the test phase may be necessary to increase older adults' ability to access recollection processes and correctly reject recombined pairs. For instance, an older face paired with an older name at study (e.g., Delbert Crawford), but then appearing with a noticeably younger name (e.g., Brayden Hofsted) at test involves a detectable change in schematic support (e.g., schematic support at study, no schematic support at test), which could be used to make the necessary correct rejection. Older adults may be able to access pre-existing knowledge that a previously presented face (e.g., an older man's face) should likely be paired with an age-congruent (older person's) name (e.g., Delbert Crawford) and not an age-incongruent (younger person's) name (e.g., Brayden Hofsted) at test. Accessing such pre-existing knowledge may also apply to instances in which, for example, an older face is paired with a younger name at study but then recombined with an older name at test given the occurrence of a salient change from an age mismatch (i.e., no schematic support) at study to an age match at test. Noticing either of these types of incompatibilities with respect to this pre-existing schema for the age of faces and names within associative pairs at test could therefore provide access to recollection-based, rather than familiarity-based, processes during retrieval. Indeed, previous work has shown that older, relative to younger adults are more prone to familiarity-based false recognition (Castel & Craik, 2003; Gallo, Bell, Beier, & Schacter, 2006; Gallo, Cotel, Moore, & Schacter, 2007; Jennings & Jacoby, 1997). However, when distinctive information is available (e.g., via perceptual richness) at the time of retrieval, older adults can search memory for explicit recollection of previously encountered content via the distinctiveness heuristic and recall-to-reject processes (Gallo et al., 2007). Moreover, when the components within associative pairs are semantically related at study, but are recombined to form unrelated pairs at test, both younger and older adults can use recall-to-reject processing to reject critical lures (Patterson, Light, Van Ocker, & Olfman, 2009). With respect to the current framework, distinct changes in schematic support may allow older adults to leverage recall-to-reject processes during retrieval to reduce their associative false alarm rates.

While changes in schematic support have the potential to reduce age-related associative memory deficits in episodic LTM memory, it is also possible that such support can reduce robust age-related associative deficits not only during LTM intervals, but also those previously observed even at brief STM retention intervals (e.g., as short as 500 ms; Chen & Naveh-Benjamin, 2012). Since older adults are thought to recruit familiarity, but not recollection, processes in a relatively automatic fashion, increasing access to more recollection-based processing at the time of retrieval may aid in reducing age-related associative memory deficits across both STM and LTM retention intervals. As such, we might expect that imposing an associative test condition in which a mismatch in age category between face and name components occurs from study to test might provide a noticeable change in schematic support via access to intact semantic memory, allowing participants to actually recollect contextual details at the time of retrieval, rather than rely solely on familiarity. In the current study, we examined the influence of changes in schematic support from study to test (Experiments 1 and 2) and the retrieval mechanisms associated with these changes – recollection vs. familiarity (Experiment 2).

Experiment 1: the role of schematic support in associative short-term and long-term memory

In the current experiment we examined whether *changes* in schematic support between the components comprising face–name pairs can be used to reduce age-related associative deficits at both STM and LTM retention intervals. Previous work indicates that older adults' episodic memory performance can benefit from schematic support cues, which increase access to relatively intact semantic memory resources (e.g., Castel, 2005; McGillivray & Castel, 2010). As it is traditionally conceptualized in the literature, the presence of schematic support within face–name pairs refers to instances in which the age category of the face and the name within a pair is congruent. In the context of an item and associative recognition test paradigm, however, this age-congruency between the face and name within a pair is unlikely to assist older adults in correctly rejecting typically "recombined" pairs from study to test. For example, the schematic support available during the encoding of an older face paired with an older person's name is unlikely to reduce older adults' high associative false alarm rate because in standard associative test paradigms recombined pairs involve the same level of schematic support at study and at test (e.g., the same older face paired with a *different* older name). As such, it seems that a *change* in schematic support from study to test would be necessary to reduce older adults' high associative false alarm rates. In other words, if schematic support is present at study (e.g., older face–older name), the removal of such support at test (e.g., older face–younger name) should provide a salient cue increasing the likelihood that older adults would correctly reject this pair on the basis of the noticeable change in schematic support. The same applies to the opposite case wherein no schematic support is present at study but is provided at test.

In the current study, our experimental manipulation involved comparing a "control" associative test condition in which no change in schematic support occurred from study to test and an associative test condition in which a change did occur. Specifically, we manipulated *changes* in schematic support from study to test during a continuous recognition task examining the influence of these factors at both STM and LTM retention intervals within the same experimental design (see Chen & Naveh-Benjamin, 2012). As existing paradigms used to examine STM and LTM processes are typically quite different, the current continuous recognition task paradigm is beneficial for making meaningful comparisons between these two memory processes.

Under normal circumstances, schematic support cues are present within face–name pairs in that the perception of the age of a person's face typically is consistent with the age category to which their name belongs. Knowledge of age consistent face–name schemas is acquired throughout the lifespan as new exemplars are encountered and maintained within semantic memory. In an experimental setting, if a younger face is originally presented with a younger name it will be encoded as compatible with a high degree of schematic support. However, subsequent encounters of the same younger face presented with a name from an "older age" category may engage recollection processes involving explicit recall of the original presence of schematic support, which is now absent with respect to the recombined face–name pair. In this experimental context, the same potential benefits might apply to instances in which no schematic support exists during the presentation of a face–name pair (e.g., younger-face, older-name) at study, but changes to a recombined pair in which schematic support is present (e.g., younger-face, younger-name) at test. In this case, no traditional schematic support is available at study (e.g., younger-face, older-name), but, crucially, schematic support later emerges during the corresponding recombination test event (e.g., younger-face, younger-name). Given that a change in the level of schematic support has occurred in both of the aforementioned examples, we would expect benefits in each of these contexts when included as subtypes within an experimental associative memory test condition. Such processes should increase the likelihood of correctly rejecting such a recombined face–name pair. As such, the primary goal of Experiment 1 was to leverage older adults' access to these pre-existing schemas, conceivably preserved in semantic memory, in an attempt to increase recollection-based retrieval processes. In turn, increased access to recollection-based retrieval, potentially via recall-to-reject processes, should aid in reducing false alarm rates characteristic of the age-related associative memory deficit.

We predicted an overall age-related associative memory deficit wherein the decline in performance for associative relative to item component memory tests should be larger for older compared to younger adults. Our baseline conditions included tests of memory for single faces or single names for item tests and face-name associative test pairs. In the baseline associative test condition, termed "no change" associative tests, no change in schematic support from study to test occurred during recombination test events (e.g., young face-young name at study and young face-with a different young name at test -or- young face–old name at study and young face-with a different old name at test). Related to our experimental test condition, termed "change" associative tests, we predicted that when the level of schematic support changed from study to test, older adults' associative memory performance would improve relative to the no change associative memory test condition. Moreover, we expected this age-related associative memory performance improvement to occur in the form of a reduced false alarm rate via access to recollection processes. In essence, recombination associative test events in the "change" condition are characterized by incompatibility in the age of each component of the face–name pairs from study to test (e.g., young face–old name at study and young face–young name at test -or- young face–young name at study and young face–old name at test). We predicted that the anticipated improvement in older adults' associative memory performance would occur via a decrease in false alarm rate from the "no change" (i.e., baseline associative test condition) to the "change" recombined associative memory tests relative to the item memory tests. In other words, changes in schematic support should increase the probability of older adults' access to recollection processes (e.g., recall-to-reject) in order to correctly reject recombined pairs.

We predicted a reduction in the age-related associative deficit at LTM retention intervals. Moreover, if accessing semantic information stored within LTM can occur even over STM retention intervals, then we would expect reductions in any observed age-related associative deficit shown during short-term memory retention intervals, as well. Importantly, the predicted benefits of changes in schematic support may interact with retention interval, wherein older adults may benefit more from this type of support during LTM than during STM retention intervals.

Method

Participants

The participants included 44 undergraduate students (age range: 18–25) from the University of Missouri who participated in exchange for course-related credit and 38 older adults (age range: 65–82) from central Missouri who were compensated $15 for their time (see Table 1 for demographic information). All participants were healthy physically and mentally, had no known memory

Table 1
Demographic information for Experiment 1 and Experiment 2.

Experiment	N	Proportion (female)	Age (years)	Education (years)
Experiment 1				
Younger	44	.64	19.16 (1.54)	12.75 (1.33)
Older	38	.76	72.08 (4.69)	15.11 (1.93)
Experiment 2				
Younger	35	.57	18.66 (0.94)	12.71 (1.23)
Older	34	.65	71.15 (4.43)	15.06 (1.63)

Note. The values for age and education depict means (standard deviations).

deficits, and had normal or corrected-to-normal visual acuity. The proportion of males and females was similar in each age group, however, as in many studies on age-related memory differences the older adults had significantly more formal education than younger adults, $t(80) = 6.50$, $p < .001$.

Stimuli and materials

The stimuli consisted of faces, names, and face–name pairs. The faces used in the current experiment, previously normed and categorized with respect to age and gender, were taken from the FACES database (Ebner, Riediger, & Lindenberger, 2010; Minear & Park, 2004). In total, 63 faces from each of four age–gender categories were selected (e.g., younger male, older male, younger female, older female). Ostensibly older and younger male and female first names were compiled from the official Social Security Administration of the United States of America website (www.ssa.gov) list of popular baby names by decade. Younger first names were sampled from three decades including the 1980s, 1990s, and 2000s, and older first names were sampled from the 1920s, 1930s, and 1940s. Surnames, were compiled from a website listing common family names prevalent in the United States (www.names.mongabay.com).

In order to examine whether younger and older adults actually perceived these first and last name combinations as “younger” or “older”, we had an independent group of 11 younger and 11 older adults who did not participate in the actual experiment perform a name rating task. In this name rating task participants were asked to: “Please rate the following name according to how young or old the name appears to you”, using the entirety of a Likert-type scale ranging from 1 (definitely young) to 8 (definitely old) and making a button press using keys 1–8 on the computer keyboard to record their response. Each participant rated a total of 400 first and last name combinations. Of these names, the exemplars rated as the most representative (63 per category) of each age and gender category (young male: $M_{rating} = 3.30$, $SD_{rating} = 1.79$; old male: $M_{rating} = 6.75$, $SD_{rating} = 1.39$; young female: $M_{rating} = 3.14$, $SD_{rating} = 1.73$; old female: $M_{rating} = 6.90$, $SD_{rating} = 1.32$) were selected and used as the name stimuli in the present experiment. There were an equal number of male and female and younger and older faces and names. Faces, which subtended 5.8° × 7.3° of visual angle, were presented at the center of the computer monitor and directly above the names (first and last names), which were presented in Courier New 24-point, bold-faced font. The experimental parameters were controlled electronically using E-Prime 2.0 software (Psychology Software Tools, Pittsburg, PA). E-Prime 2.0 was run via a Dell Optiplex 755 desktop computer and the stimuli were presented on a 20-in. ASUS flat-screen LED monitor with a resolution of 1920 × 1080 (refresh rate: 60 Hz).

Procedure

Participants, seated at a viewing distance of approximately 57 cm, were required to perform a modified version of a recently developed continuous recognition task (Chen & Naveh-Benjamin, 2012). In this task, participants are continuously presented with either a study phase event or one of two types of test phase events; see Fig. 1. During each event, a prompt (e.g., Study, Item, Assoc) was presented in Arial 22-point, italicized font above the stimulus to remind participants of the task during each type of event. During the “Study” events (lasting 5 s), the participants were required to simply study the face–name pair presented on the computer monitor. During the “Item” test events (lasting 5 s), participants were presented with either a previously presented or completely new face or name in isolation and were required to indicate, via button press, whether or not they had seen that item previously within the same experimental block using keys labeled ‘yes’ (i.e., old item) and ‘no’ (i.e., new item). During the “Assoc” test events (lasting 5 s), participants were presented with a face–name pair that had either been presented previously within the same block (i.e., intact pair), or with a novel face–name pair consisting of the components from two distinct face–name pairs presented previously within the same block (i.e., recombined pair). Participants were required to press the key labeled ‘yes’ if the associative test pair was presented intact and the key labeled ‘no’ if the pair presented during the associative test event was a recombination. Stimuli during all test events remained on the computer monitor for a total of 5 s regardless of when the participant initiated their response. An interstimulus interval (500 ms) was presented between each event.

The number of events presented between a given study event and its corresponding test event determined the duration of the specific retention interval, which occurred within the domain of either short-term or long-term memory. Short-term memory retention intervals were comprised of durations of 500 ms (e.g., 0 events between a given study and test event), 5.5 s (e.g., 1 event between), or 10.5 s (e.g., 2 events between). Long-term memory retention intervals were 85.5 s (e.g., 17 events between), 90.5 s (e.g., 18 events between), or 95.5 s (e.g., 19 events between).

The experimental manipulations of interest occurred during the associative test events across all STM and LTM retention intervals as a function of the congruency of the age-category of the components presented at study and test. In the “no change” associative test conditions, the face–name pairs either belonged to the same (see Fig. 2a; no change: age congruent–congruent) or different (see Fig. 2b; no change: age incongruent–incongruent) age

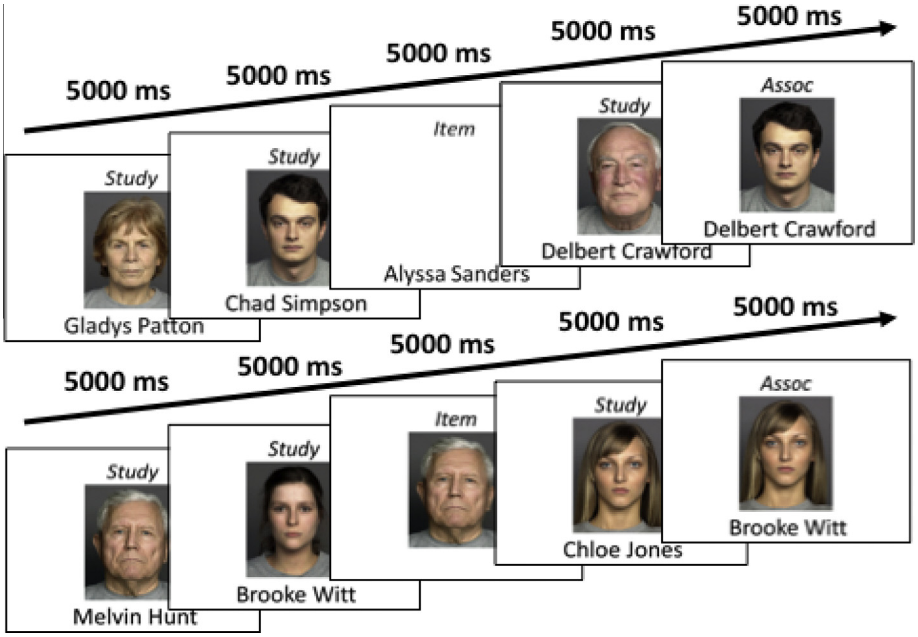

Fig. 1. *Schematic of the continuous recognition task used in Experiments 1 and 2*: Depiction of several study and test events from the continuous recognition task paradigm used in Experiment 1 and Experiment 2, with each event presented for 5000 ms each and a 500 ms inter-stimulus interval between each event. Each event was either a "Study," "Item," or "Assoc" and was accompanied by a face–name pairing, or a single face or name. Associative test pairs were displayed either intact or recombined using stimuli shown earlier during the event sequence.

category during *both* the study events and corresponding test events. In the "change" associative test conditions, the face–name pairs either belonged to the same (see Fig. 2d; change: age congruent–incongruent) or different (see Fig. 2c; change: age incongruent–congruent) age category at study and, crucially, these experimental conditions involve a change in the level of schematic support when a given test event appears. As such, the crucial manipulation was whether or not the age-congruency between the face and name within a given face–name pair changes from study to test. In the "change" associative test conditions (Fig. 2c and d), the age-congruency between the face and name within a given pair changes from study to test. In contrast, in the "no change" conditions (Fig. 2a and b), no change in schematic support occurs from study to test, merely a recombination of the item components.

In total, there were 72 study events and 96 test events (half item, half associative) in each of the 3 blocks of the continuous recognition task. Of the total number of item tests, half were old and half were new and half tested the name component while the other half tested the face component corresponding to the face–name pairs presented during the study events. Of the associative tests, half involved the presentation of intact face–name pairs presented previously within the same task block. The other half of associative tests involved the presentation of one of the four types (described above) of recombined test pairs composed of face and name components presented earlier within the same block of the continuous recognition task. There were an equal number of test events involving each type of recombination (9 total across all three blocks). The presentation order of the three experimental blocks was counterbalanced (6 block orders total) across participants within each age group. Participants were offered a break in between each block of the experiment. Prior to beginning the three experimental blocks, participants completed a shortened practice version of the continuous recognition task to ensure comprehension of the task.

Results

Overall memory accuracy analysis

We measured overall response accuracy by computing separately the proportion of hits and the proportion of false alarms (see Table 2) and then subtracting the proportion of false alarms from the proportion of hits (henceforth, proportion hits minus false alarms) in each experimental condition for each participant in each age group; see Fig. 3. We averaged performance in the face and name item tests to yield composite item performance values. We then submitted the proportion hits minus false alarms values to a $2 \times 2 \times 3$ repeated-measures analysis of variance (ANOVA) including the between-subjects factor of age (younger, older adults) and the within-subjects factors of retention interval (STM, LTM), and test (item, and the two measures based on the associative tests: change and no change). Two of the 38 older adults (both female) consistently exhibited chance-level performance (e.g., 2 *SD*'s below the group means) and were not included in the following group level analyses.

There was a main effect of age, $F(1,78) = 22.46$, $p < .001$, $\eta_p^2 = .22$), confirming that younger adults ($M = .55$, $SD = .15$) performed with greater accuracy than older adults ($M = .40$, $SD = .14$). There was a significant main effect of retention interval, $F(1,78) = 234.05$, $p < .001$, $\eta_p^2 = .75$), indicating that performance was higher during

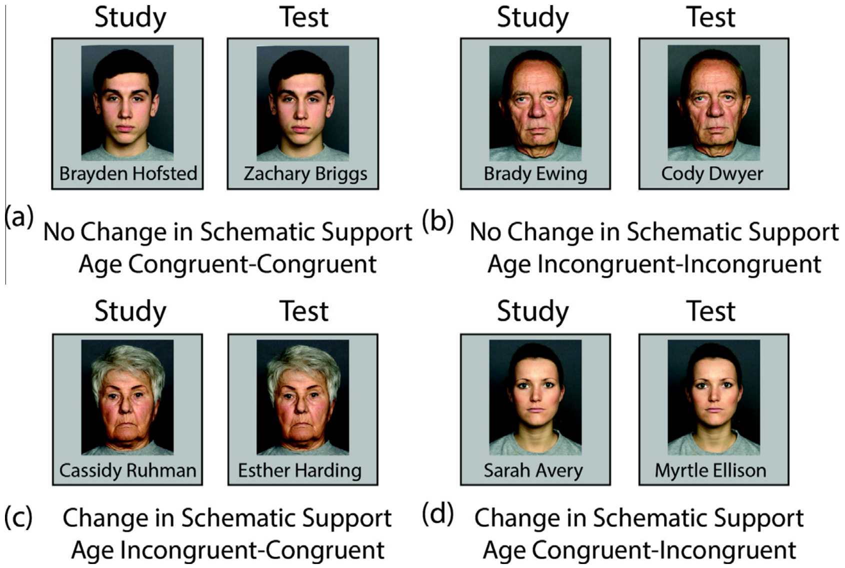

Fig. 2. *Depiction of the change and no change recombination subtypes for associative memory study and test events*: Depiction of the four subtypes of no change (panels a and b) and change (panels c and d) conditions (recombination subtypes depicted) during associative memory study and test events used in Experiment 1 and Experiment 2.

Table 2
Experiment 1: Mean response accuracy values (with standard deviations) for each experimental condition for younger and older adults.

	Item	Change	No change
STM			
Hits			
Younger	.85 (.09)	.80 (.16)	.81 (.13)
Older	.83 (.08)	.81 (.14)	.76 (.15)
False alarms			
Younger	.15 (.09)	.18 (.12)	.18 (.11)
Older	.21 (.10)	.29 (.21)	.23 (.14)
H–FA			
Younger	.70 (.13)	.62 (.21)	.63 (.19)
Older	.62 (.14)	.52 (.23)	.53 (.20)
LTM			
Hits			
Younger	.68 (.17)	.69 (.20)	.71 (.21)
Older	.63 (.16)	.59 (.21)	.60 (.22)
False alarms			
Younger	.14 (.08)	.24 (.14)	.34 (.18)
Older	.19 (.12)	.38 (.24)	.52 (.20)
H–FA			
Younger	.54 (.18)	.45 (.26)	.37 (.25)
Older	.44 (.15)	.21 (.26)	.08 (.24)

STM retention intervals ($M = .61$, $SD = .10$) compared to LTM retention intervals ($M = .35$, $SD = .14$). Additionally, there was a main effect of test, $F(2,156) = 39.70$, $p < .001$, $\eta_p{}^2 = .34$), indicating a difference between the three test conditions. Bonferroni-corrected pairwise comparisons indicated that performance was significantly higher during the item test events ($M = .58$, $SD = .09$) compared to the no change ($M = .40$, $SD = .13$) associative test events ($p < .001$). Performance during the item test events was also significantly higher than in the change associative test events ($M = .45$, $SD = .15$, $p < .001$). The difference in performance in the change and no change associative test events was marginal, but non-significant ($p = .08$).

Importantly, there was a significant three-way interaction between age, test, and retention interval, $F(2,156) = 3.93$, $p = .02$, $\eta_p{}^2 = .05$).[1] To further explore this significant triple interaction, we focused our follow-up analyses on examining the age by test interaction at each type of retention interval by examining the data corresponding to the STM and LTM intervals separately. The age by test interaction corresponding to the STM intervals was not significant, $F(2,156) = 0.16$, $p = .83$, indicating that no age-related associative deficit was present during the STM retention intervals. For the LTM intervals, however, there was a significant interaction between age and test, $F(2,156) = 7.78$, $p = .001$, $\eta_p{}^2 = .09$. In summary, older adults' associative memory performance was lower compared to the younger adults; however, this age-related associative memory deficit was present during LTM but not STM intervals.

Follow-up 2 × 2 repeated-measures ANOVAs examining interaction comparisons were carried out on the interaction of age and test during the LTM intervals.[2] The

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[1] We note that the overall interaction between age and test was also significant, $F(2,156) = 4.39$, $p = .02$, ${}_p{}^2 = .05$). Follow-up 2 × 2 repeated-measures ANOVAs indicated this interaction was significant when comparing item test and no change associative test performance, $F(1,78) = 13.71$, $p < .001$, ${}_p{}^2 = .15$, but not significant when comparing the item test and change associative test performance, $F(1,78) = 3.32$, $p = .07$. No interaction between age and test was present when comparing the two associative test conditions, $F(1,78) = .68$, $p = .41$.

[2] Analysis of the LTM retention sub-intervals (85, 90, 95 s) indicated that overall performance was the most accurate (using proportion hits minus false alarms) in the short retention interval (85 s: $M = .43$, $SD = .21$) compared to either of the longer intervals (90 s: $M = .35$, $SD = .20$, $p = .02$; 95 s: $M = .34$, $SD = .16$, $p = .02$). Likewise, reaction times during retrieval were the shortest in the short retention interval (e.g., 85 s: $M = 2{,}611$ ms, $SD = 236$ ms; 90 s: $M = 2{,}649$ ms, $SD = 208$ ms; 95 s: $M = 2{,}643$ ms, $SD = 219$ ms), though the effect was not significant, $F(2,156) = 1.79$, $p = .17$.

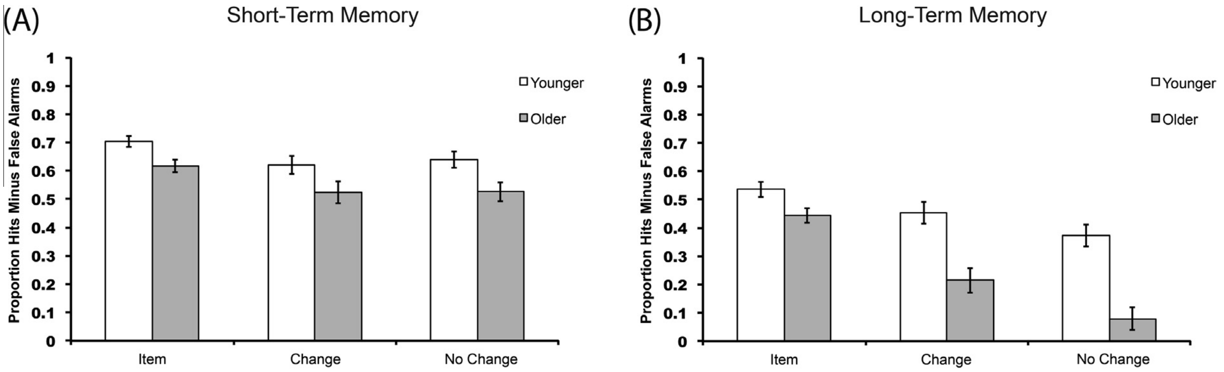

Fig. 3. *Experiment 1 results depicting the proportion hits minus false alarms for each experimental condition*: Experiment 1 behavioral results are presented for (a) STM intervals and (b) LTM intervals. In both panels, the abscissa depicts the various test conditions while younger and older adults' recognition memory performance (proportion hits minus false alarms) is plotted along the ordinate. Error bars represent the standard error of the mean in each test condition at each retention interval.

Table 3
Summary of statistical main effects, interactions, and follow-up analyses from Experiment 1.

Experiment 1	Effect type	Factor(s)	Statistic
Hits	Main Effect	Age	$F(1,78) = 5.13$, $p = .03$, $\eta_p^2 = .06$
	Main Effect	Test Type	$F(2,156) = 2.26$, $p = .11$
	Main Effect	Retention Interval	$F(1,78) = 101.89$, $p < .001$, $\eta_p^2 = .57$
	Interaction	Age × Test	$F(2,156) = 1.25$, $p = .29$
	Interaction	Age × Test × Retention Interval	$F(2,156) = 1.30$, $p = .28$
False alarms	Main Effect	Age	$F(1,78) = 21.64$, $p < .001$, $\eta_p^2 = .22$
	Main Effect	Test Type	$F(2,156) = 36.43$, $p < .001$, $\eta_p^2 = .22$
	Main Effect	Retention Interval	$F(1,78) = 71.29$, $p < .001$, $\eta_p^2 = .48$
	Interaction	Age × Test	$F(2,156) = 3.71$, $p = .06$
	Interaction	Age × Test × Retention Interval	$F(2,156) = 4.31$, $p = .02$, $\eta_p^2 = .05$
	Interaction Follow-up	STM Intervals: Age × Test	$F(2,156) = 1.26$, $p = .28$
	Interaction Follow-up	LTM Intervals: Age × Test	$F(2,156) = 4.75$, $p = .01$, $\eta_p^2 = .06$
	Interaction Follow-up	LTM: Age × Test (Item vs. No Change)	$F(1,78) = 8.42$, $p = .005$, $\eta_p^2 = .10$
	Interaction Follow-up	LTM: Age × Test (Item vs. Change)	$F(1,78) = 4.13$, $p = .05$, $\eta_p^2 = .05$
	Interaction Follow-up	LTM: Age × Test (Change vs. No Change)	$F(1,78) = 0.96$, $p = .33$
	Follow-up *t*-test	LTM: Younger (Item vs. No Change)	$t(43) = 6.43$, $p < .001$
	Follow-up *t*-test	LTM: Younger (Item vs. Change)	$t(43) = 4.31$, $p < .001$
	Follow-up *t*-test	LTM: Younger (Change vs. No Change)	$t(43) = 3.86$, $p < .001$
	Follow-up *t*-test	LTM: Older (Item vs. No Change)	$t(35) = 8.49$, $p < .001$
	Follow-up *t*-test	LTM: Older (Item vs. Change)	$t(35) = 4.07$, $p < .001$
	Follow-up *t*-test	LTM: Older (Change vs. No Change)	$t(35) = 3.97$, $p < .001$
H–FA	Main Effect	Age	$F(1,78) = 22.46$, $p < .001$, $\eta_p^2 = .22$
	Main Effect	Test Type	$F(2,156) = 39.70$, $p < .001$, $\eta_p^2 = .34$
	Main Effect	Retention Interval	$F(1,78) = 234.05$, $p < .001$, $\eta_p^2 = .75$
	Interaction	Age × Test	$F(2,156) = 4.39$, $p = .02$, $\eta_p^2 = .05$
	Interaction	Age × Test × Retention Interval	$F(2,156) = 3.93$, $p = .02$, $\eta_p^2 = .05$
	Interaction Follow-up	STM Intervals: Age × Test	$F(2,156) = 0.16$, $p = .83$
	Interaction Follow-up	LTM Intervals: Age × Test	$F(2,156) = 7.78$, $p = .001$, $\eta_p^2 = .09$
	Interaction Follow-up	LTM: Age × Test (Item vs. No Change)	$F(1,78) = 18.79$, $p < .001$, $\eta_p^2 = .19$
	Interaction Follow-up	LTM: Age × Test (Item vs. Change)	$F(1,78) = 7.08$, $p = .009$, $\eta_p^2 = .08$
	Interaction Follow-up	LTM: Age × Test (Change vs. No Change)	$F(1,78) = 0.98$, $p = .32$
	Follow-up *t*-test	LTM: Younger (Item vs. No Change)	$t(43) = 5.36$, $p < .001$
	Follow-up *t*-test	LTM: Younger (Item vs. Change)	$t(43) = 2.96$, $p = .005$
	Follow-up *t*-test	LTM: Younger (Change vs. No Change)	$t(43) = 2.43$, $p = .02$
	Follow-up *t*-test	LTM: Older (Item vs. No Change)	$t(35) = 10.44$, $p < .001$
	Follow-up *t*-test	LTM: Older (Item vs. Change)	$t(35) = 4.67$, $p < .001$
	Follow-up *t*-test	LTM: Older (Change vs. No Change)	$t(35) = 2.84$, $p = .007$

interaction between item test and no change associative test performance and age was significant, $F(1,78) = 18.79$, $p < .001$, $\eta_p^2 = .19$, revealing an age-related associative deficit. Additionally, there was an interaction in the comparison of item test and change associative test performance and age, $F(1,78) = 7.08$, $p = .009$, $\eta_p^2 = .08$. However, there was no interaction when comparing the two associative test conditions and age, $F(1,78) = 0.98$, $p = .32$ (see summary of statistical main effects, interactions, and follow-up analyses for this experiment in Table 3).

Separate follow-up paired-samples *t*-tests on the significant 2 × 2 interaction comparisons for each age group indicated that younger adult performance was significantly higher in the item test condition ($M = .54$, $SD = .18$) compared to either the change ($M = .45$, $SD = .26$; $t(43) = 2.96$, $p = .005$), or no change associative test conditions ($M = .37$, $SD = .25$; $t(43) = 5.36$, $p < .001$). There was also a significant difference in performance when comparing the change and no change associative test conditions, $t(43) = 2.43$, $p = .02$). For the older adults, performance was significantly higher in the item test condition ($M = .44$, $SD = .15$) compared to either the change ($M = .21$, $SD = .26$; $t(35) = 4.67$, $p < .001$), or no change associative test conditions ($M = .08$, $SD = .24$; $t(35) = 10.44$, $p < .001$). Performance in the change associative test condition was significantly higher than for the no change associative test condition, $t(35) = 2.84$, $p = .007$). Notably, the observed difference between performance in the item test and no change associative test condition was twice as large for older relative to younger adults. These follow-up analyses reveal that the schematic support manipulation improved associative memory performance for both younger and older adults.

Separate analysis of hits and false alarms

In addition to analyzing the proportion hits minus false alarms values, we conducted the same analyses for the proportion hits and proportion false alarms values separately to examine whether the overall age-related deficit observed was driven by a difference between younger and older adults in the proportion of hits or the proportion of false alarms. Below, we report results from the analyses corresponding to these two separate measures of performance (see Table 2). For the proportion hits values, there was a significant main effect of age, $F(1,78) = 5.13$, $p = .03$, $\eta_p^2 = .06$, indicating an overall difference in hit rate between the younger ($M = .76$, $SD = .11$) and older ($M = .70$, $SD = .11$) adults. There was a main effect of retention interval, $F(1,78) = 101.89$, $p < .001$, $\eta_p^2 = .57$, wherein hit rates were higher for the STM ($M = .81$, $SD = .07$) compared to the LTM intervals ($M = .65$, $SD = .12$). There was no main effect of test, $F(2,156) = 2.26$, $p = .11$, indicating no significant difference in the hit rates for the item tests ($M = .75$, $SD = .08$), change ($M = .72$, $SD = .11$), and no change ($M = .72$, $SD = .11$) associative memory tests. Importantly, there was no significant interaction between age and test, $F(2,156) = 1.25$, $p = .29$, nor was there a significant three-way interaction between age, test, and retention interval, $F(2,156) = 1.30$, $p = .28$. As such, the age-related associative memory deficit at LTM retention intervals revealed in the proportion hits minus false alarms analysis (see above) was not driven by a difference in hit rates between younger and older adults.

With respect to the separate analysis pertaining to the proportion of false alarms, there was a significant main effect of age, $F(1,78) = 21.64$, $p < .001$, $\eta_p^2 = .22$, indicating an overall higher false alarm rate for the older ($M = .30$, $SD = .10$) relative to the younger ($M = .20$, $SD = .09$) adults. As in the proportion hits minus false alarms analysis, consideration of the proportion of false alarms in isolation yielded a main effect of test, $F(2,156) = 36.43$, $p < .001$, $\eta_p^2 = .32$. Bonferroni-corrected pairwise comparisons indicated that the false alarm rate was significantly higher in the no change associative test ($M = .32$, $SD = .09$) condition compared to the item test condition ($M = .18$, $SD = .07$, $p = .008$), and compared to the change associative test condition ($M = .27$, $SD = .12$, $p < .001$). Finally, the false alarm rate was significantly higher in the change test condition compared to the item test condition ($p < .001$). There was also a main effect of retention interval, $F(1,78) = 71.29$, $p < .001$, $\eta_p^2 = .48$, wherein false alarm rates were significantly higher during the LTM ($M = .30$, $SD = .09$) compared to the STM intervals ($M = .20$, $SD = .07$).

Importantly, there was a significant three-way interaction between the factors of age, test, and retention interval, $F(2,156) = 4.31$, $p = .02$, $\eta_p^2 = .05$.[3] We focused our follow-up analyses on examining the age by test interaction at each retention interval by examining the false alarm data corresponding to the STM and LTM intervals separately.

Consistent with the proportion hits minus false alarms analyses, there was no interaction between age and test for the proportion of false alarms during STM retention intervals, $F(2,156) = 1.26$, $p = .28$. However, there was an interaction between age and test with respect to the proportion of false alarms occurring during the LTM retention intervals, $F(2,156) = 4.75$, $p = .01$, $\eta_p^2 = .06$. Follow-up 2 × 2 repeated-measures ANOVAs indicated a significant interaction between item test and no change associative test performance and age, $F(1,78) = 8.42$, $p = .005$, $\eta_p^2 = .10$. Additionally, there was an interaction between item test and change associative test performance and age, $F(1,78) = 4.13$, $p = .05$, $\eta_p^2 = .05$. However, there was no interaction when comparing the two associative test conditions and age, $F(1,78) = .96$, $p = .33$. As was the case in the proportion hits minus false alarms analysis, the age-related associative memory deficit, driven by higher false alarm rates for older compared to younger adults, was present during LTM but not STM retention intervals.

Separate follow-up paired-samples *t*-tests for the significant age by item and no change associative test and age by item and change associative test interactions for each age group indicated that younger adult false alarm rates during LTM retention intervals were significantly higher in the no change associative test condition ($M = .34$, $SD = .18$) compared to either the change associative ($M = .24$, $SD = .14$; $t(43) = 3.86$, $p < .001$), or item test conditions ($M = .15$, $SD = .08$; $t(43) = 6.43$, $p < .001$). Also, false alarm rates during LTM intervals were significantly higher in the change associative compared to the item test conditions, $t(43) = 4.31$, $p < .001$). For the older adults, false alarm rates during LTM retention intervals were significantly higher in the no change associative test condition ($M = .52$, $SD = .20$) ompared to either the change associative ($M = .38$, $SD = .24$; $t(35) = 3.97$, $p < .001$), or item test conditions ($M = .19$, $SD = .12$; $t(35) = 8.49$, $p < .001$). Additionally, for

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[3] The overall interaction between the factors of age and test was borderline, $F(2,156) = 3.71$, $p = .06$, but not significant.

older adults, false alarm rates during LTM intervals were significantly higher in the change associative compared to the item test conditions, $t(35) = 4.07$, $p < .001$).[4] Overall, older and younger adults' associative memory performance during LTM retention intervals was improved via a decrease in false alarm rates in the change compared to the no change associative test condition.

Discussion

An age-related associative memory deficit was evident during LTM but not STM retention intervals. Consistent with previous findings in the literature, this age-related LTM deficit was driven by higher false alarm rates for the older compared to younger adults. Interestingly, the findings from the current experiment are in support of the predicted results and indicate that changes in schematic support occurring from study events to test events can improve associative memory performance in both younger and older adults. Specifically, the false alarm rates were lower in the experimental change condition compared to the no change associative test condition for both age groups. Conceivably, younger and older adults were able to take advantage of the change in schematic support from study to test to improve their associative memory. Of primary interest to the current work, these findings implicate the role of changes in schematic support in reducing susceptibility to item familiarity for older adults, who may instead adopt recollection processes in service of correctly rejecting recombined associative pairs at test. While this pattern of results is intriguing, examination of the putative mechanisms giving rise to these schematic support benefits to associative LTM is an important next step.

Experiment 2: the influence of recollection- and familiarity-based retrieval mechanisms in reducing age-related associative memory deficits via schematic support

The results from Experiment 1 indicate benefits of changes in schematic support in improving younger and older adults' associative LTM. The mechanisms underlying this benefit, however, remain unclear. One possibility is that such support affords younger, but especially, older adults the opportunity to access recollection-based processes rather than relying solely on familiarity-based processes, which remain relatively intact in older adults (Davidson & Glisky, 2002; Jacoby et al., 2005; Kilb & Naveh-Benjamin, 2011; Light et al., 2000). To examine this possibility, in Experiment 2, we used a modified version of the continuous recognition task (Chen & Naveh-Benjamin, 2012) from Experiment 1 in conjunction with the remember–know–guess (RKG) paradigm (Gardiner, Ramponi, & Richardson-Klavehn, 1998; Tulving, 1985). In the classic remember–know paradigm and modified remember–know–guess paradigm, a secondary judgment task "R", "K", or "G" is required after an "old" response to a test event is made. According to dual-process theories, these secondary response judgments are thought to distinguish the participants' access to recollection (i.e., "remember" responses) compared to familiarity (i.e., "know" responses) processes at the time of retrieval. However, viewed through the lens of signal detection theory and more recent continuous dual-process signal detection model approaches, "remember" and "know" responses may underlie varying levels of memory trace strength rather than dissociable retrieval processes, per se (e.g., Donaldson, 1996, but see also Wixted & Mickes, 2010). As such, the addition of the "guess" response option is attempt to further distinguish relatively weak memory traces from those reaching criterion for emitting a "know" response or an even relatively higher criterion for a "remember" response.

The first goal of Experiment 2 was to replicate the findings from Experiment 1. Second, Experiment 2 was designed to examine the retrieval mechanisms underlying reductions in the age-related associative memory deficit via changes in schematic support. If these support benefits permit older adults' access to recollection-based processes (e.g., via recall-to-reject mechanisms), allowing older adults to capitalize on the fact that, for example, the young face shown at test was actually seen with a young name during study, and hence reject the current association of this young face with an old name, then improvements in older adults' memory performance in our change relative to no change associative test condition should be associated with "remember" judgments. Alternatively, if the reduction in the age-related associative deficit is due to improvements in already intact familiarity-based processes, wherein, for example, the new young face–old name pair at retrieval simply looks unfamiliar, then performance improvements in the change condition over the no change condition should be associated with a greater proportion of "know" judgments.

Method

Participants

The participants included a new group of 35 undergraduate students (age range: 18–22) from the University of Missouri who participated in exchange for course-related credit and a new group of 34 older adults (age range: 65–83) from central Missouri who were compensated $15 for their time (see Table 1 for demographic

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[4] We submitted the false alarm rate values from Experiment 1 to a 2 × 2 × 4 repeated-measures ANOVA including the factors of age (younger, older), retention interval (STM, LTM), and associative test recombination subtype (no change: incongruent–incongruent, no change: incongruent–congruent, change: congruent–incongruent, change: incongruent–congruent). There was a main effect of recombination subtype in terms of false alarm rates, $F(3,234) = 16.00$, $p < .001$, $_p^2 = .17$. Bonferroni-corrected pairwise comparisons indicated that there was a significant difference in false alarm rate when comparing the change: incongruent–congruent ($M = .30$, $SD = .15$) and change: congruent–incongruent ($M = .22$, $SD = .14$) subtypes corresponding to the change associative tests ($p = .001$). Further pairwise comparisons also indicated that performance in the no change: congruent–congruent ($M = .36$, $SD = .13$) test subtype (i.e., true baseline associative memory test), produced a significantly higher false alarm rate compared to the no change: incongruent–incongruent ($M = .25$, $SD = .11$, $p < .001$). No significant patterns were present with respect to the interaction of age and recombination subtype, $F(3,234) = .66$, $p = .57$, nor the three-way interaction of age, recombination subtype, and retention interval, $F(3,234) = 1.21$, $p = .31$.

information). All participants were healthy physically and mentally, had no known memory deficits, and had normal or corrected-to-normal visual acuity. The proportion of males and females was similar in each age group, however, as in many studies on age-related memory differences the older adults had significantly more formal education than younger adults, $t(67) = 6.76$, $p < .001$.

Stimuli and materials

The same face and name stimuli used in Experiment 1 were used in Experiment 2. Again, the experimental parameters were controlled electronically using E-Prime 2.0 software (Psychology Software Tools, Pittsburg, PA). E-Prime 2.0 was run via a Dell Optiplex 755 desktop computer and the stimuli were presented on a 20-in. ASUS flat-screen LED monitor with a resolution of 1920 × 1080 (refresh rate: 60 Hz).

Procedure

The procedure used in Experiment 2 was identical to that of Experiment 1 with the following exceptions, which were necessary in order to incorporate a newly included ‘ ‘remember–know–guess” procedure. Again, participants performed a continuous recognition task during which either faces, names, or face–name pairs were presented during study events (5 s) and test events (5 s). However, after each test event, if a “yes” (i.e., akin to an “old”) response was made to indicate that the participant had seen that item or pair of items during a previously presented study event, a secondary judgment response prompt appeared below the stimulus test probe, which remained on the computer monitor, asking the question, “How do you remember? Context? Familiar? Guess?” Participants had 5 s to respond with their secondary judgment using keys labeled “Context” (akin to “R”), “Familiar” (akin to “K”), “Guess” (akin to “G”). Instructions for these responses were adapted from the “R–K–G” procedure used by Gardiner et al. (1998). After test events in which a “no” response was made, the stimulus test probe remained on the screen for 5 s, but no secondary judgment prompt appeared below the stimulus test probe.

Finally, to accommodate the additional time required for the secondary response judgments (i.e., 5 s), the number of events presented between a given study event and its corresponding test event, determining the duration of the specific retention interval within the domain of either short-term or long-term memory, differed from those used in Experiment 1. The inter-stimulus-interval remained constant at 500 ms. Short-term memory retention intervals were comprised of durations of 500 ms (e.g., 0 events between a given study and test event) or 5.5 s (e.g., 1 event between). The 10.5-s interval (e.g., 2 events between) used in Experiment 1 was not included in Experiment 2. The long-term memory retention intervals used in Experiment 2 were similar, but on average shorter, compared to the LTM retention intervals used in Experiment 1 given the inclusion of the secondary judgment response period. The number of events between each study and test event was modified such that only 8, 9, or 10 intervening events occurred during the LTM retention intervals. This resulted in LTM retention intervals ranging from 55 to 85 s, which varied throughout a given task block given the difference in duration between study events (5 s) and the total length of test events and subsequent secondary judgment response periods (10 s).

There were 72 study events, 48 item test events (half old, half new), and 48 associative test events (half intact, half recombined). Half of the test events occurred after STM retention intervals while the other half occurred after LTM retention intervals. Half of the item tests included tests of the face component and the other half included tests of the name component from the original face–name pair presented during corresponding study events. Finally, of the recombined associative memory tests, half included change recombination tests with the other half including no change recombination tests. In Experiment 2, participants completed only two blocks of the continuous recognition task and were instructed to take a short break in between the two blocks. Block order was counterbalanced across participants within each age group. Prior to beginning the two experimental task blocks, participants completed a shortened practice version of the continuous recognition paradigm to ensure comprehension of the task.

Results

Overall accuracy as a function of schematic support

As in Experiment 1, we measured overall response accuracy by computing separately the proportion of hits and the proportion of false alarms (see Table 4) and then subtracting the proportion of false alarms from the proportion of hits (henceforth, proportion hits minus false alarms) in each experimental condition for each participant in each age group; see Fig. 4. We averaged performance in the face and name item tests to yield composite item performance values. We then submitted

Table 4
Experiment 2: Mean response accuracy values (with standard deviations) for each experimental condition for younger and older adults.

	Item	Change	No change
STM			
Hits			
Younger	.94 (.06)	.93 (.10)	.95 (.06)
Older	.93 (.10)	.91 (.08)	.93 (.08)
False alarms			
Younger	.11 (.10)	.08 (.10)	.06 (.07)
Older	.26 (.11)	.27 (.26)	.21 (.26)
H–FA			
Younger	.83 (.12)	.85 (.14)	.89 (.11)
Older	.67 (.21)	.64 (.28)	.72 (.27)
LTM			
Hits			
Younger	.80 (.12)	.82 (.13)	.82 (.15)
Older	.81 (.12)	.77 (.16)	.83 (.16)
False alarms			
Younger	.08 (.07)	.24 (.17)	.29 (.19)
Older	.28 (.18)	.46 (.26)	.69 (.19)
H–FA			
Younger	.72 (.13)	.58 (.22)	.53 (.24)
Older	.53 (.20)	.31 (.25)	.14 (.18)

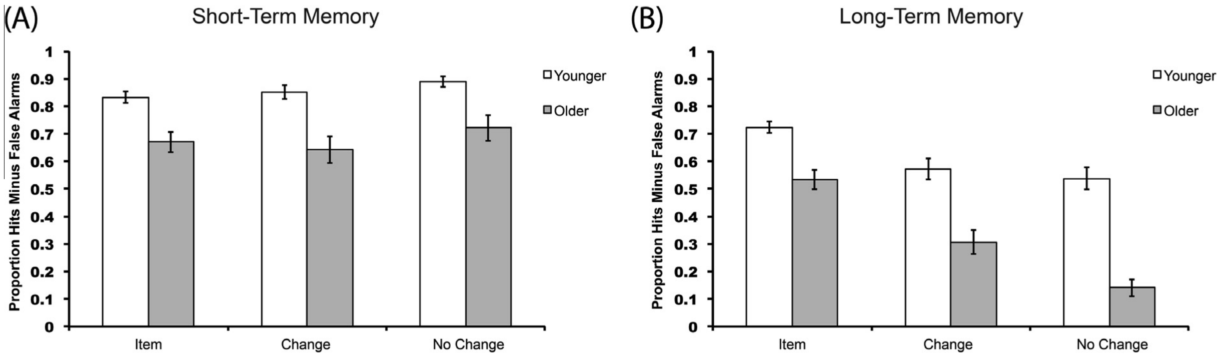

Fig. 4. *Experiment 2 results depicting the proportion hits minus false alarms for each experimental condition*: Experiment 2 overall behavioral results are presented for (a) STM intervals and (b) LTM intervals. In both panels, the abscissa depicts the various test conditions while younger and older adults' recognition memory performance (proportion hits minus false alarms) is plotted along the ordinate. Error bars represent the standard error of the mean in each test condition at each retention interval.

the proportion hits minus false alarms values to a 2 × 2 × 3 mixed repeated-measures ANOVA including the between-subjects factor of age (younger, older adults) and the within-subjects factors of retention interval (STM, LTM), and test (item, and the two measures based on the associative tests: change and no change).

This analysis revealed a main effect of age, $F(1,67) = 36.58$, $p < .001$, $\eta_p^2 = .35$), indicating that younger adults ($M = .73$, $SD = .16$) performed with greater accuracy than older adults ($M = .50$, $SD = .16$). There was a main effect of retention interval, $F(1,67) = 368.87$, $p < .001$, $\eta_p^2 = .85$, wherein performance was significantly higher during STM ($M = .77$, $SD = .13$) compared to LTM ($M = .47$, $SD = .12$) retention intervals. Additionally, there was a main effect of test condition, $F(2,134) = 28.52$, $p < .001$, $\eta_p^2 = .30$. Bonferroni-corrected pairwise comparisons indicated a significant difference in performance in the item test ($M = .69$, $SD = .11$) condition compared to both the change ($M = .59$, $SD = .14$; $p < .001$) and no change ($M = .57$, $SD = .12$; $p < .001$) associative test conditions. There was no significant difference in performance when comparing the two associative test conditions ($p = .62$).

Consistent with the results from Experiment 1, in Experiment 2 the three-way interaction between age, test, and retention interval was significant, $F(2,134) = 5.51$, $p = .006$, $\eta_p^2 = .08$, indicating that the age-related deficit varied as a function of retention interval.[5] Separate 2 × 3 ANOVAs were used to analyze proportion hits minus false alarms corresponding to younger and older adults in each test condition as a function of STM and LTM retention interval. No interaction between age and test was present in the analysis corresponding to performance during STM retention intervals, $F(2,134) = .89$, $p = .41$. The analysis examining performance during the LTM retention intervals did reveal a significant interaction between age and test, $F(2,134) = 7.78$, $p = .001$, $\eta_p^2 = .10$, indicating that the age-related deficit was driven by differences in associative memory performance between younger and older adults during the LTM retention intervals. To examine the locus of the interaction between age and test at the LTM retention intervals, separate 2 × 2 repeated-measures ANOVAs were used. The age by test interaction was significant when comparing performance in the item test and the no change associative memory test conditions, $F(1,67) = 14.63$, $p < .001$, $\eta_p^2 = .18$. The comparison of performance in the item test and change associative test conditions did not reveal a significant interaction between the factors of age and test, $F(1,67) = 2.51$, $p = .12$. Moreover, there was a significant interaction between age and test when comparing the change and no change associative memory test conditions, $F(1,67) = 5.27$, $p = .03$, $\eta_p^2 = .07$ (see Table 6 for a summary of statistical analyses for this experiment).

Separate follow-up paired-samples *t*-tests for each age group were used to examine the significant age by test interactions age by item and no change, and age by change and no change observed during the LTM retention intervals. For the younger adults' performance during the LTM retention intervals there was a significant difference between item test ($M = .72$, $SD = .17$) and both the change ($M = .57$, $SD = .24$; $t(34) = 5.52$, $p < .001$) and no change ($M = .54$, $SD = .21$; $t(34) = 5.22$, $p < .001$) associative memory tests. Additionally, for the younger adults, there was no difference in performance during tests of change and no change associative memory, $t(34) = .88$, $p = .39$). For the older adults, there was a significant difference in test performance during the LTM retention intervals between the item test ($M = .53$, $SD = .17$) and both the change ($M = .31$, $SD = .24$; $t(33) = 5.92$, $p < .001$) and no change ($M = .14$, $SD = .21$; $t(33) = 9.71$, $p < .001$) associative memory tests. Crucially, in contrast to the pattern observed for the younger adults, performance was significantly higher for the older adults in the change compared to the no change associative test condition, $t(33) = 3.95$, $p < .001$, indicating that the schematic support manipulation benefited the older but not younger adults, reducing the

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[5] The overall interaction between age and test was significant, $F(2,134) = 5.15$, $p = .007$, $_p^2 = .07$. Follow-up 2 × 2 ANOVAs revealed a significant interaction between age and test in the comparison of performance in the item and no change associative test conditions, $F(1,67) = 10.04$, $p = .002$, $_p^2 = .13$. When comparing performance in the item test compared to change associative test conditions, however, the interaction between age and test was marginal, but not significant, $F(1,67) = 3.25$, $p = .08$. Finally, no interaction between the factors of age and test was present when comparing the two associative test conditions, $F(1,67) = 1.96$, $p = .17$.

age-related associative memory deficit observed during the LTM retention intervals.

Separate analysis of hits and false alarms

Separate analyses were carried out for the proportion of hits and the proportion of false alarms. The analysis examining the proportion of hits indicated only a main effect of retention interval, $F(1,67) = 128.92$, $p < .001$, $\eta_p^2 = .66$, but no main effect of age, $F(1,67) = .49$, $p = .49$, nor a main effect of test, $F(2,134) = 2.58$, $p = .09$. The interactions between age and test, $F(2,134) = 1.02$, $p = .36$, and between age, test, and retention interval, $F(2,134) = .98$, $p = .37$, were not significant. These results are similar to those reported in Experiment 1.

The analysis examining the proportion of false alarms revealed a main effect of age, $F(1,67) = 39.55$, $p < .001$, $\eta_p^2 = .37$), indicating a higher proportion of false alarms for older ($M = .36$, $SD = .15$) compared to younger adults ($M = .14$, $SD = .15$). There was a main effect of retention interval, $F(1,67) = 195.86$, $p < .001$, $\eta_p^2 = .75$, wherein the false alarm rate was significantly higher during LTM ($M = .34$, $SD = .11$) compared to STM ($M = .16$, $SD = .11$) retention intervals. Additionally, there was a main effect of test condition, $F(2,134) = 42.21$, $p < .001$, $\eta_p^2 = .39$. Bonferroni-corrected pairwise comparisons indicated a significant difference in false alarm rates in the item test ($M = .18$, $SD = .09$) condition compared to both the change ($M = .26$, $SD = .14$; $p < .001$) and no change ($M = .31$, $SD = .11$; $p < .001$) associative test conditions. There was also a significant difference in false alarm rates when comparing the two associative test conditions ($p < .001$).

The analysis of the proportion of false alarms revealed a significant three-way interaction between the factors of age, test, and retention interval, $F(2,134) = 10.29$, $p < .001$, $\eta_p^2 = .13$.[6] Separate follow-up analyses examining false alarm rates at STM and LTM retention intervals indicated no interaction between age and test during STM retention intervals, $F(2,134) = .64$, $p = .50$, but did reveal that this interaction was significant during LTM retention intervals, $F(2,134) = 14.21$, $p < .001$, $\eta_p^2 = .18$.

Follow-up 2 × 2 ANOVAs were used to explore the age by test interaction during LTM retention intervals. The age by test interaction was significant when comparing performance in the item test and the no change associative memory test conditions, $F(1,67) = 21.73$, $p < .001$, $\eta_p^2 = .25$. The comparison of performance in the item test and change associative test conditions did not reveal a significant interaction between the factors of age and test, $F(1,67) = .19$, $p = .66$. Moreover, there was a significant interaction between age and test when comparing the change and no change associative memory test conditions, $F(1,67) = 19.35$, $p < .001$, $\eta_p^2 = .22$. Importantly, follow-up paired-samples *t*-tests confirmed that there was no difference in the false alarm rates in the associative test conditions during LTM retention intervals for younger adults (change: $M = .24$, $SD = .17$, no change: $M = .29$, $SD = .19$; $t(34) = 1.44$, $p = .16$). For older adults, however, the false alarm rates during LTM retention intervals corresponding to the change ($M = .46$, $SD = .26$) tests were significantly lower than for the no change ($M = .69$, $SD = .19$) associative tests, $t(33) = 7.39$, $p < .001$. Consistent with the proportion hits minus false alarms analysis, the analysis pertaining to the proportion of false alarms indicated an age-related deficit during only the LTM retention intervals. Older adults' false alarm rates decreased as a result of changes in schematic support, reducing the age-related associative deficit.

Benefits of schematic support in long-term memory as a function of remember–know judgments

In order to examine the influence of recollection- and familiarity-based processes in facilitating the schematic support benefits observed during the LTM retention intervals in the overall analysis described above, we calculated the proportion of hits and proportion of false alarms (see Table 5) and computed proportion hits minus false alarms values as a function of secondary judgment response types, namely, "context" (i.e., "R"), "familiar, (i.e., "K"), and "guess" (i.e., "G"). We note that only participants who made at least one "R" and "K" response in all test conditions in both STM and LTM retention intervals (17 younger and 17 older adults) were included in subsequent group-level analyses (see Table 5 and Fig. 5). Proportion hits minus false alarm values corresponding to "guess" responses were not included in the following analyses as they constituted only a very small proportion of the test events overall (averaged across test and retention interval) for younger ($M = .02$, $SD = .05$) and older ($M = .09$, $SD = .12$) adults. Given that we computed separate hit rates, false alarm rates, and proportion hits minus false alarms values for "R" and "K" judgments, the hit rates and false alarm rates for the "R" and "K" data in Table 5 do not sum to equal the hit rates and false alarm rates of the aggregate data provided in Table 4. To provide an example illustrating our calculation strategy, if, out of 10 old items, 5 were "R" judgments, and 5 were "K" judgments, and if 4/5 of the test responses corresponding to the "R" judgments were correct, and 2/5 of the test responses corresponding to the "K" judgments were correct, then the hit rate for this particular participant would have been .80 for accuracy as a function of "R" in this particular condition, and their hit rate would have been .40 with respect to accuracy as a function of "K" in this particular condition. While we present the proportion hits minus false alarms as a function of "R" and "K" responses for both STM and LTM retention intervals (see Table 5 for means and *SD*'s and Fig. 5), we focused planned comparisons as a function of the "R" and "K" responses on the LTM retention interval performance

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[6] There was a significant interaction between age and test, $F(2,134) = 6.26$, $p = .004$, ${}_p^2 = .09$. Follow-up 2 × 2 repeated-measures ANOVAs revealed a significant interaction between age and test in the comparison of performance in the item and no change associative test conditions, $F(1,67) = 10.24$, $p = .002$, ${}_p^2 = .13$. When comparing performance in the item test compared to change associative test conditions, however, the interaction between age and test was not significant, $F(1,67) = .66$, $p = .42$. Finally, a significant interaction between the factors of age and test was present when comparing the change and no change associative test conditions, $F(1,67) = 9.56$, $p = .003$, ${}_p^2 = .13$. Importantly, follow-up paired-samples *t*-tests confirmed that there was no difference in the false alarm rates in the associative test conditions for younger adults (change: $M = .16$, $SD = .11$, no change: $M = .17$, $SD = .11$; $t(34) = .78$, $p = .44$). For older adults, however, the false alarm rates corresponding to the change ($M = .37$, $SD = .24$) tests were significantly lower than for the no change ($M = .45$, $SD = .20$) associative tests, $t(33) = 5.35$, $p < .001$.

Table 5
Experiment 2: Mean response accuracy values (with standard deviations) as a function of remember–know judgments for each experimental condition for younger and older adults.

	Item R	Item K	Change R	Change K	No change R	No change K
STM						
Hits						
Younger	.93 (.13)	.96 (.05)	.93 (.13)	.90 (.20)	.97 (.06)	.96 (.08)
Older	.93 (.17)	.96 (.06)	.94 (.13)	.86 (.27)	.86 (.25)	.96 (.08)
False alarms						
Younger	.02 (.05)	.14 (.11)	.00 (.00)	.05 (.11)	.01 (.03)	.05 (.11)
Older	.14 (.21)	.24 (.14)	.13 (.22)	.30 (.20)	.14 (.22)	.18 (.27)
H–FA						
Younger	.91 (.17)	.82 (.12)	.93 (.13)	.84 (.22)	.96 (.06)	.91 (.17)
Older	.79 (.24)	.72 (.16)	.81 (.27)	.55 (.38)	.72 (.32)	.78 (.30)
LTM						
Hits						
Younger	.80 (.17)	.85 (.16)	.87 (.14)	.71 (.28)	.82 (.16)	.80 (.28)
Older	.68 (.27)	.86 (.14)	.76 (.26)	.74 (.25)	.82 (.18)	.89 (.15)
False alarms						
Younger	.01 (.04)	.13 (.13)	.18 (.26)	.24 (.23)	.14 (.26)	.27 (.30)
Older	.10 (.16)	.26 (.18)	.30 (.37)	.47 (.28)	.58 (.31)	.65 (.33)
H–FA						
Younger	.78 (.15)	.72 (.17)	.69 (.32)	.46 (.35)	.68 (.29)	.53 (.49)
Older	.58 (.27)	.60 (.23)	.46 (.36)	.27 (.32)	.24 (.30)	.24 (.36)

Table 6
Summary of statistical main effects, interactions, and follow-up analyses from Experiment 2.

Experiment 2	Effect type	Factor(s)	Statistic
Hits	Main Effect	Age	$F(1,67) = 0.49$, $p = .49$
	Main Effect	Test Type	$F(2,134) = 2.58$, $p = .09$
	Main Effect	Retention Interval	$F(1,67) = 128.92$, $p < .001$, $\eta_p^2 = .66$
	Interaction	Age × Test	$F(2,134) = 1.02$, $p = .36$
	Interaction	Age × Test × Retention Interval	$F(2,134) = 0.98$, $p = .37$
False alarms	Main Effect	Age	$F(1,67) = 39.55$, $p < .001$, $\eta_p^2 = .37$
	Main Effect	Test Type	$F(2,134) = 42.21$, $p < .001$, $\eta_p^2 = .39$
	Main Effect	Retention Interval	$F(1,67) = 195.86$, $p < .001$, $\eta_p^2 = .75$
	Interaction	Age × Test	$F(2,134) = 6.26$, $p = .004$, $\eta_p^2 = .09$
	Interaction	Age × Test × Retention Interval	$F(2,134) = 10.29$, $p < .001$, $\eta_p^2 = .13$
	Interaction Follow-up	STM Intervals: Age × Test	$F(2,134) = 0.64$, $p = .50$
	Interaction Follow-up	LTM Intervals: Age × Test	$F(2,134) = 14.21$, $p < .001$, $\eta_p^2 = .18$
	Interaction Follow-up	LTM: Age × Test (Item vs. No Change)	$F(1,67) = 21.73$, $p < .001$, $\eta_p^2 = .25$
	Interaction Follow-up	LTM: Age × Test (Item vs. Change)	$F(1,67) = 0.19$, $p = .66$
	Interaction Follow-up	LTM: Age × Test (Change vs. No Change)	$F(1,67) = 19.35$, $p < .001$, $\eta_p^2 = .22$
	Follow-up *t*-test	LTM: Younger (Change vs. No Change)	$t(34) = 1.44$, $p = .16$
	Follow-up *t*-test	LTM: Older (Change vs. No Change)	$t(33) = 7.39$, $p < .001$
H–FA	Main Effect	Age	$F(1,67) = 36.58$, $p < .001$, $\eta_p^2 = .35$
	Main Effect	Test Type	$F(2,134) = 28.52$, $p < .001$, $\eta_p^2 = .30$
	Main Effect	Retention Interval	$F(1,67) = 368.87$, $p < .001$, $\eta_p^2 = .85$
	Interaction	Age × Test	$F(2,134) = 5.15$, $p = .007$, $\eta_p^2 = .07$
	Interaction	Age × Test × Retention Interval	$F(2,134) = 5.51$, $p = .006$, $\eta_p^2 = .08$
	Interaction Follow-up	STM Intervals: Age × Test	$F(2,134) = 0.89$, $p = .41$
	Interaction Follow-up	LTM Intervals: Age × Test	$F(2,134) = 7.78$, $p = .001$, $\eta_p^2 = .10$
	Interaction Follow-up	LTM: Age × Test (Item vs. No Change)	$F(1,67) = 14.63$, $p < .001$, $\eta_p^2 = .18$
	Interaction Follow-up	LTM: Age × Test (Item vs. Change)	$F(1,67) = 2.51$, $p = .12$
	Interaction Follow-up	LTM: Age × Test (Change vs. No Change)	$F(1,67) = 5.27$, $p = .03$, $\eta_p^2 = .07$
	Follow-up *t*-test	LTM: Younger (Item vs. No Change)	$t(34) = 5.22$, $p < .001$
	Follow-up *t*-test	LTM: Younger (Item vs. Change)	$t(34) = 5.52$, $p < .001$
	Follow-up *t*-test	LTM: Younger (Change vs. No Change)	$t(34) = 0.88$, $p = .39$
	Follow-up *t*-test	LTM: Older (Item vs. No Change)	$t(33) = 9.71$, $p < .001$
	Follow-up *t*-test	LTM: Older (Item vs. Change)	$t(33) = 5.92$, $p < .001$
	Follow-up *t*-test	LTM: Older (Change vs. No Change)	$t(33) = 3.95$, $p < .001$
	Planned *t*-test	LTM: Younger (Change R vs. No Change R)	$t(16) = 0.14$, $p = .89$
	Planned *t*-test	LTM: Younger (Change K vs. No Change K)	$t(16) = -.58$, $p = .57$
	Planned *t*-test	LTM: Older (Change R vs. No Change R)	$t(16) = 2.27$, $p = .038$
	Planned *t*-test	LTM: Older (Change K vs. No Change K)	$t(16) = 0.44$, $p = .66$

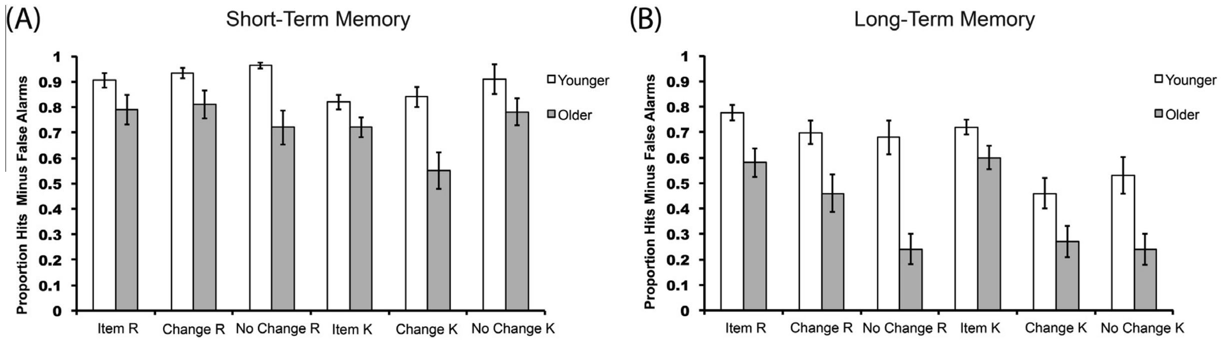

Fig. 5. *Experiment 2 results depicting the proportion hits minus false alarms for each experimental condition as a function of secondary remember–know judgments*: Experiment 2 behavioral results as a function of "remember–know" secondary judgments are presented for (a) STM intervals and (b) LTM intervals. In both panels, the abscissa depicts the test conditions being compared as a function of remember and know judgments while younger and older adults' recognition memory performance (proportion hits minus false alarms) is plotted along the ordinate. Error bars represent the standard error of the mean in each test condition at each retention interval.

data corresponding to only the associative test conditions in which the benefits of schematic support were evident for older but not younger adults.

These planned comparisons were carried out using separate paired-samples *t*-tests comparing LTM performance (proportion hits minus false alarms) in each age group to examine the change and no change associative test comparison as a function of secondary "remember" and "know" responses. For the younger adults, there was no significant difference in performance in the change ($M = .69$, $SD = .32$) and no change ($M = .68$, $SD = .28$) associative test events in which "remember" responses were made, $t(16) = .14$, $p = .89$. Additionally, younger adult performance did not differ significantly in the change ($M = .46$, $SD = .35$) and no change ($M = .53$, $SD = .49$) associative test events as a function of "know" responses, $t(16) = -.58$, $p = .57$. For the older adults, however, a different pattern was evident. Specifically, performance in the change condition ($M = .46$, $SD = .36$) was significantly higher than in the no change ($M = .24$, $SD = .30$) associative test condition, when "remember" responses were made, $t(16) = 2.27$, $p = .038$. However, no significant difference in performance between these two associative test conditions (change: $M = .27$, $SD = .32$; no change: $M = .24$, $SD = .36$) was evident when "know" responses were made, $t(16) = .44$, $p = .66$. These results suggest that the benefits due to the change in schematic support from study to test observed in Experiment 2, which reduced the age-related deficit, allowed older adults to access recollection-based processes to improve their associative memory performance.

Discussion

The results from the current experiment replicated and extended the overall findings from Experiment 1, indicating that changes in schematic support can improve older adults' associative memory and, under some circumstances, even alleviate age-related associative memory deficits observed in LTM. In the current experiment, we again found no age-related associative memory deficit for face–name pairs during STM retention intervals, consistent with the findings from Experiment 1. Finally, the results from the current experiment indicate that the age-related deficit during LTM retention intervals was driven by high false alarm rates exhibited by older relative to younger adults during associative memory tests, which were reduced significantly when changes in schematic support occurred (e.g., in the change test condition).

The results from the current experiment related to the "remember–know" judgments further extend the findings from Experiments 1 and 2 and are consistent with our predictions, indicating that changes in schematic support increase older adults' access to recollection processes at the time of retrieval. Importantly, performance in the change and no change associative test conditions as a function of remember–know judgments varied with age. Specifically, a significant increase in older adults' associative memory performance was observed in the change relative to the no change condition tests when "remember" judgments were made. However, a different pattern emerged for the younger adults. Namely, performance was higher for the younger adults during "remember" than "know" judgments regardless of associative memory test condition. This finding suggests an important age-related distinction between the role of recollection and familiarity during the retrieval of face–name pairs in these change and no change associative memory tests.

While the presence or *level of schematic support* during study events varied in the current experiment (e.g., no change: young face–young name or change: young face–old name), the crucial manipulation relates to whether or not a *change in schematic support* occurred from the study to the test events. In the case of the change associative tests, the level of schematic support changed from the study to the test events (e.g., congruent-to-incongruent - or- incongruent-to-congruent). These changes conceivably allowed older adults to access pre-existing age consistent face–name schemas, triggering recollection processes to aid in the explicit recall that the level of schematic support had changed. For instance, when viewing a younger face and younger name during a study event, the pair is consistent with the pre-existing schema that a "young" face tends to be paired with a "young" name. However, if the same young face is presented with an older name during the corresponding test event, a change occurs making the recombined face–name pair inconsistent with this pre-existing schema stored in semantic memory and, more importantly, the original level of schematic support encountered during the study event (e.g., young face–young name). Detection of these incompatibilities at the time of retrieval was associated with "remember" judgments for older adults, potentially representing recall-to-reject processes, allowing the older adults to correctly reject recombined pairs.

General discussion

In line with our main prediction, in both Experiments 1 and 2 we observed associative memory performance improvements when changes in the level of schematic support occurred from study to test. However, both Experiments 1 and 2 revealed that these benefits were present only when recombined associative test events occurred across LTM compared to STM retention intervals. Importantly, Experiment 2 revealed that, for older adults, recollection-based processes mediated these benefits during retrieval. The results from the "remember–know" analyses in Experiment 2 suggest that older adults relied on familiarity-based processes during attempts at retrieval of face–name pairings when no change in schematic support occurred. In the current experiments, imposing conditions in which younger and older adults had the opportunity to access pre-existing schemas from semantic memory to improve detection of recombined face and name components led to increased associative memory performance.

In Experiment 1, both younger and older adults benefited from our schematic support manipulation in the form of improved associative memory. In Experiment 2, however, only the older adults improved their associative memory performance, alleviating the age-related associative deficit observed during LTM retention intervals, when comparing item test and change associative test performance. In order to better compare these observed patterns and improve statistical power, we combined the data from both Experiments 1 and 2 to analyze younger and older adults' performance in each of the test conditions during STM and LTM retention intervals. This cross-experimental analysis, including Experiment (1, 2) as a between-subjects factor, indicated the same pattern of main effects, a significant age by test interaction, and a significant triple interaction between age, test, and retention interval observed in Experiments 1 and 2. Importantly, the four-way interaction between age, test, retention interval and experiment was not significant.[7] Subsequent analyses examining the cross-experimental three-way interaction converged with the results from Experiments 1 and 2 in isolation indicating that the age-related associative memory deficit was present at LTM but not STM retention intervals. Moreover, this age-related deficit was present in each age by test interaction comparison. Finally, subsequent analyses indicated that while both younger and older adults benefited from the schematic support manipulation via improved associative memory performance in the change compared to no change tests, the benefit was larger for the older relative to the younger adults.[8]

Despite these small differences in the magnitude of the benefits of changes in schematic support observed in Experiment 1 and Experiment 2, several patterns were consistently observed in both experiments. First, an age-related associative memory deficit was observed during LTM retention intervals, replicating this ubiquitous finding from the literature, (e.g., Old & Naveh-Benjamin, 2008), and also recent findings from a study that employed a continuous recognition task to examine age-related deficits during a variety of memory retention intervals (Chen & Naveh-Benjamin, 2012). Second, in both experiments we found that no age-related deficit was present during STM retention intervals. While this finding is in contrast to the findings from Chen and Naveh-Benjamin (2012), it is important to note that in the former study, face–scene pairs were presented, whereas in the current experiments binding between faces and names was required. Forming associations between faces and scenes may be relatively more difficult than faces and names, given that memory for face–name pairs is especially relevant for social purposes, with each component (e.g., face, name) comprising an aspect of personal identity.

Moreover, evidence from the STM and working memory literature on age-related associative or binding deficits during STM retention intervals is somewhat mixed (for a review see Allen, Brown, & Niven, 2013), with some studies finding evidence of age-related deficits (e.g., Borg et al., 2011; Experiment 2, Brown & Brockmole, 2010; Chen & Naveh-Benjamin, 2012; Cowan et al., 2006; Fandakova et al., 2014; Mitchell et al., 2000) and others not finding this pattern (Brockmole et al., 2008; Experiment 1, Brown & Brockmole, 2010; Parra et al., 2009; Read et al., 2015; Rhodes et al., 2016). Intriguingly, other recent findings indicate that the presence or absence of age-related binding deficits in visual STM depends on the type of binding (e.g., shape–color vs. item–location binding) and whether or not a secondary task (e.g., articulatory suppression) concurrent to the primary STM task is imposed (Peterson & Naveh-Benjamin, 2016). As such, whether all types of visual STM binding processes remain intact across the lifespan remains unclear, with this recent evidence highlighting several factors that seem to be important for

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[7] Cross-experimental overall analysis: Main effects: (age: $F(1,145) = 59.81$, $p < .001$, $_p^2 = .29$; retention interval: $F(1,145) = 578.28$, $p < .001$, $_p^2 = .80$; test: $F(2,290) = 65.75$, $p < .001$, $_p^2 = .22$). Interactions: (age by test: $F(2,290) = 9.94$, $p < .001$, $_p^2 = .06$; age by test by retention interval: $F(2,290) = 8.23$, $p < .001$, $_p^2 = .05$; age by test by retention interval by experiment: $F(2,290) = 1.16$, $p = .31$).

[8] Cross-experimental subsequent analyses: Interactions: (age by test by retention interval: $F(2,294) = 8.45$, $p < .001$, $_p^2 = .05$; STM interval-age by test: $F(2,294) = .31$, $p = .73$; LTM interval-age by test: $F(2,294) = 15.14$, $p < .001$, $_p^2 = .09$). LTM follow-up interactions age by test: (age by item vs. change: $F(1,147) = 9.74$, $p = .002$, $_p^2 = .06$; age by item vs. no change: $F(1,147) = 34.03$, $p < .001$, $_p^2 = .19$; age by change vs. no change: $F(1,147) = 5.14$, $p = .03$, $_p^2 = .03$). Paired-samples t-tests: (younger adults: item vs. change: $t(78) = 5.65$, $p < .001$; item vs. no change: $t(78) = 7.53$, $p < .001$; change vs. no change: $t(78) = 2.37$, $p = .02$; older adults: item vs. change: $t(69) = 7.33$, $p < .001$; item vs. no change: $t(69) = 14.28$, $p < .001$; change vs. no change: $t(69) = 4.74$, $p < .001$).

future investigations examining the role of aging in visual STM binding processes.

Finally, in both Experiment 1 and Experiment 2, the age-related associative LTM deficit was driven mostly by higher false alarm rates for older compared to younger adults during tests of associative memory. This is consistent with previous findings that the age-related associative deficit in LTM is largely driven by disproportionately high false alarm rates, relative to hit rates, exhibited by older adults (Castel & Craik, 2003; Cohn et al., 2008; Kilb & Naveh-Benjamin, 2011). Importantly, in both experiments, older adults' false alarm rates during change associative memory tests were reduced relative to no change associative memory tests in which no change in the level of schematic support occurred from study to test. It should be noted that the benefits of schematic support reported here seem to be mediated by a different mechanism than those underlying unitization processes, which have recently been shown to aid in older adults' associative memory (e.g., Ahmad, Fernandes, & Hockley, 2015; Bastin et al., 2013). Whereas the benefits of unitization seem to manifest during the encoding phase (e.g., "brother" and "hood" unitized into "brotherhood"), in the current work, the benefits of the schematic support occurred only once the test probe face–name pair appears and the participant notices that a change in the level of schematic support from the study phase has occurred. Thus, the incompatibility with respect to the face–name age schema between study and corresponding test events was the crucial factor mediating the current schematic support benefits.

Retrieval mechanisms

The results of Experiment 2 provide insight into the retrieval mechanism(s) which older adults were able to use to improve their associative memory performance. These results suggest that older adults were able to reduce their LTM associative memory deficit by making use of recollection processes during attempts at retrieval of associations between face–name pairs when changes in schematic support occurred from study to test. Specifically, for older adults, secondary "remember" judgments were associated with greater accuracy during the change but not the no change associative memory test condition. In contrast, no difference in older adults' performance in the no change compared to change associative tests was evident when subsequent "know" judgments were made. For younger adults, performance was higher in both of the associative test conditions when "remember" compared to "know" judgments were made. Because "remember" judgments are typically associated with recollection processes, the results from Experiment 2 indicate that older adults gained increased access to these more elaborative retrieval processes, aiding in associative memory performance during the change tests. As recollection processes tend to decline with age, older adults are thought to rely mostly on familiarity processes during retrieval (Davidson & Glisky, 2002; Jacoby et al., 2005; Kilb & Naveh-Benjamin, 2011; Light et al., 2000). Importantly, in Experiment 2, increased access to recollection processes improved older adult's associative memory performance.

Notably, when viewed through the lens of dual-process theories, the current results indicate that changes in schematic support afford older adults access to recollection processes (i.e., "remember" judgments) instead of relying solely on familiarity (i.e., "know" judgments) during tests of associative memory. Alternatively, it may be the case that the strength of the memory trace was simply stronger in the change condition relative to the no change associative test condition. For instance, according to signal detection theory and more recent continuous dual-process signal detection model approaches to recognition memory, "remember" and "know" responses may underlie varying levels of memory trace strength rather than dissociable retrieval processes, per se (e.g., Donaldson, 1996; Wixted & Mickes, 2010). From this perspective, changes in schematic support may simply heighten the strength of the memory trace leading older adults to judge that a sufficient amount of recollection had occurred at the time of associative test events causing them to make "remember" judgments. Indeed, in the current work, "remember" judgments following responses during change associative test events were associated with a reduced age-related associative deficit. However, with respect to the current findings, given that we did not collect auxiliary measures of memory strength (e.g., confidence judgments) in addition to the secondary responses in Experiment 2, it is difficult to ascertain the extent to which a continuous dual-process signal-detection model account should be favored over a dual-process explanation.

Compatible with a dual-process theoretical account of recognition memory, it may be the case that these benefits of schematic support are mediated by a recall-to-reject strategy. Recall-to-reject processing is associated with recollection-based recognition memory. In the context of associative memory, a strong sense of recollection that item components, presented within a recombined pair at test, were not originally paired together at the time of encoding can result in correctly rejecting the pair. For instance, in the current experiments, younger and older adults had the opportunity to take advantage of recall-to-reject processes if they were able to access pre-existing schematic knowledge maintained in semantic memory that a previously presented face (e.g., an older man's face) would likely be paired with an age-congruent (older person's) name (e.g., Delbert Crawford) and not an age-incongruent (young) name (e.g., Brayden Hofsted) at test. Such access should also apply to instances in which, for example, an older face is paired with a younger name at study but then recombined with an older name at test given the change from an age mismatch at study to an age match at test. Noticing either type of inconsistency with respect to pre-existing schemas for the age of faces and names within associative pairs at test could provide access to recollection-based, rather than familiarity-based, processes during retrieval.

Indeed, the schematic support manipulation used in Experiment 2 decreased false alarm rates for the older adults, which were much lower in the change condition ($M = .30$) compared to the no change associative test condition ($M = .58$) when "remember" judgments were made. However, this was not the case for the younger adults (“remember” judgments: change: $M = .18$; no change: $M = .14$), indicating that the older adults benefited to a relatively greater degree from changes in schematic support. Instantiation of recall-to-reject processes during the retrieval process can reduce feelings of vague familiarity, which have been shown to decrease false alarm rates (Brainerd, Reyna, & Kneer, 1995). In Experiment 2, the recollection driven reduction in false alarm rates was evident for the older adults when changes in schematic support occurred between study and test events.

Several previous reports indicate that older adults have difficulty making use of recall-to-reject based recognition (Cohn et al., 2008; Gallo et al., 2006; Healy, Light, & Chung, 2005). In contrast, other findings suggest that older adults can access recall-to-reject processes when made aware of rules pertaining to mutually exclusivity with respect to the origin of a given presentation format. For instance, informing older adults that remembering an item as having belonged to a specific presentation format when studied previously (e.g., an item presented as a picture could not have been presented as a word) can provide them with the opportunity to use recall-to-reject processing (Gallo et al., 2007). Older adults can also make use of recall-to-reject processes when initially presented semantically related pairs are recombined into unrelated pairs at test (Patterson et al., 2009). In the context of the current work, when awareness that changes to the original level of schematic support encountered at study can be used as a means to reject recombined pairs during retrieval, the probability of correct rejections is increased. In the current experiments, any such awareness occurred in the absence of explicit instruction, as we did not inform participants that a change in schematic support could be used as a recall-to-reject strategy.

Short-term and long-term memory distinctions

In the current work, the LTM-related benefits of accessing pre-existing knowledge from semantic memory via changes in schematic support were not apparent at STM intervals. Several possibilities exist regarding this distinction. First, in the current experiments, overall performance for both age groups was relatively high and no age-related deficit was apparent during STM retention intervals, perhaps precluding the type of benefits observed at LTM intervals. Second, it is possible that low-level perceptual changes in either the face or name components are more easily detectable and can be used as a basis for rejection of recombined pairs over STM compared to LTM intervals, increasing performance and obscuring any potential benefits of schematic support.

Finally, given the relatively short retention intervals imbedded within the continuous recognition task format, changes in schematic support may have occurred too rapidly to elicit any benefits to associative memory performance during STM intervals.[9] Notably, although some work indicates that semantic coding may contribute to STM processes (e.g., Klein, 1970; Shulman, 1970, 1972), other findings suggest that LTM, but not STM, processes rely on semantic coding (e.g., Baddeley, 1966; Purser & Jarrold, 2010; Tehan & Humphreys, 1995; Wickens, Born, & Allen, 1963; Wickens & Clark, 1968). In turn, encoding face–name pairs and attempting to re-activate pre-existing schematic content from semantic LTM regarding comparison of the age of the face and name components may benefit from more time, making the available benefits of changes in schematic support more likely over LTM compared to STM retention intervals.

Conclusions

The current study provides evidence indicating that older (in both Experiments 1 and 2) and younger (in Experiment 1) adults are able to implicitly take advantage of changes in schematic support from initial study presentation to corresponding test events, and that older adults do so by accessing recollection processes in service of reducing the age-related associative deficit. It remains an interesting question for future investigations as to whether or not explicitly making older and younger adults aware of strategies that involve accessing pre-existing schemas regarding the age of face–name pairs would further reduce the age-related deficit. Finally, in the current experiments, schematic support benefits were effective during LTM but not during STM retention intervals, in which the age-related associative deficit was conspicuously absent.

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[9] We note that some of the STM retention intervals used in the current experiments (e.g., 5.5 s, 10.5 s) are longer than those typically used in STM experiments.

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