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Adult Age Differences in Specific and Gist Associative Episodic Memory Across Short- and Long-Term Retention Intervals

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Age-related deficits in associative episodic memory have been widely reported, but recent research suggests that some of these deficits occur for highly specific but not gist representations. It remains undetermined whether older adults' deficits in specific associative episodic memory, observed in long-term memory, are also present in short-term memory. We used a continuous associative recognition task to address this question. Fifty young and 50 older adults studied face–scene pairs, with memory tests occurring in both short-term and long-term memory. Memory tests featured intact (old) pairs, related (similar) pairs, and unrelated (dissimilar) pairs. On short-term memory tests, older adults were less accurate in classifying related pairs, which was manifest by age-related reductions in the probability of retrieving specific memory to engage in recollection rejection. However, older adults were capable of remembering specific details in short-term memory for intact probes but were less likely to remember specific details in long-term memory. Finally, older adults were always as capable as younger adults of remembering gist details. Results suggest that older adults do at least partially encode specific representations in short-term memory, and their access to these specific representations is cue dependent—they can do so when there is a large correspondence between encoding and retrieval conditions but are less likely to engage in deeper elaboration at retrieval. This limits their ability to remember specific details of associations to suppress false recognitions in short-term memory and to engage in veridical recognition in long-term memory.

Public Significance Statement

Adult aging is associated with a loss of memory for specific details of past experiences, yet little is known about how quickly older adults forget specific representations in episodic memory. The present study shows that older adults exhibit some losses in the ability to remember specific details of past episodes almost immediately after encountering those episodes. At the same time, given the right retrieval cues in short-term memory, older adults can successfully remember some specific details of a recently encoded episode as well as younger adults. Moreover, older adults can successfully remember past episodes at gist levels of representation in both short- and long-term memory.

Keywords: episodic memory, associative memory, aging, fuzzy-trace theory

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Episodic memory, or memory for events that occurred in a specific time and place (Tulving, 1983), is susceptible to normal age-related deficits (e.g., Naveh-Benjamin & Old, 2008; Zacks et al., 2000) and representational degradation (Abadie et al., 2021; Castel et al., 2007; Greene et al., 2022; Greene & Naveh-Benjamin, 2020; Kensinger & Schacter, 1999; Koutstaal, 2003; Koutstaal et al., 1999; Koutstaal & Schacter, 1997; Luo & Craik, 2009; Radvansky & Dijkstra, 2007; Reder et al., 1986; Schacter et al., 1997; Simons et al., 2004; Stark et al., 2013; Tun et al., 1998). Older adults are less likely to remember specific details in episodic memory but tend to remember less detailed information, including the gist or meaning of an episode (for reviews, see Brainerd & Reyna, 2015; Devitt & Schacter, 2016). This view has been supported recently by studies measuring age-related differences in specific and gist memory for complex associations between components of an episode (Greene & Naveh-Benjamin, 2020), which lie at the core of episodic memory (Zimmer et al., 2006) and are especially vulnerable to age-related deficits (Naveh-Benjamin, 2000; Old & Naveh-Benjamin, 2008). Greene and Naveh-Benjamin (2020), using an associative recognition task with pictures of faces paired with pictures of scenes, demonstrated that older adults were as capable as younger adults of remembering the gist of where they

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The data and ideas in this article have not been disseminated previously. Scene stimuli can be accessed at https://bradylab.ucsd.edu/. Face stimuli can be accessed at https://faces.mpdl.mpg.de. Data and analysis scripts are available at https://osf.io/cx5uz/.

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previously saw someone (e.g., "the young man was in a park") but were less likely to remember the specific location (e.g., "Was the young man in this park, or another park?"). Such findings suggest that age-related deficits in the associative aspects of episodic memory (Naveh-Benjamin, 2000) scale with the amount of specificity that needs to be remembered (cf. Greene et al., 2022).

Here, we aimed to gain deeper insight into whether age deficits in specific associative episodic memory appear only in long-term memory, as has been shown so far (Greene et al., 2022; Greene & Naveh-Benjamin, 2020), or if these deficits occur much earlier when information can still reside actively in working memory, the temporary memory system that allows for maintaining a small subset of information for ongoing cognitive operations (Cowan, 2017). A confound exists in the current literature, in which effects of aging on memory representations that are highly specific in nature have chiefly been examined in long-term retention situations. According to fuzzy-trace theory, which posits the existence of two traces of information—a verbatim trace for the specific details of an episode, and a gist trace for the meaning of the episode—verbatim traces disintegrate with increasing interference and temporal delay (Brainerd & Reyna, 1990, 2002). Consequently, memory for specific details of an episode, such as the specific association between a face and a scene (e.g., Greene & Naveh-Benjamin, 2020), may have been forgotten, especially among older adults, by the time that information was tested on in long-term memory. This obscures whether older adults could initially establish specific representations to comparable extents as younger adults in the first place. If older adults do initially encode specific representations, then age differences in memory for specific details should be minimized (or disappear completely) under conditions that are favorable to specific memory traces. One condition that should be favorable to specific memory traces, if these have been established, is testing for specific details of an event that was just encoded when the representation for that event can still reside within working memory, where interference and temporal delay have been minimized. If age deficits in memory for specific details are absent in working memory but present in long-term memory, then older adults would be expected to initially form specific representations as well as younger adults but would then be more prone to forgetting those representations in long-term memory.

In what follows, we first discuss the relationship between working memory and long-term memory. We then consider how measuring older adults' ability to remember specific details in working memory, in addition to the standard format of doing so in long-term memory, can provide insight into when age deficits in memory for specific details emerge. Finally, we describe our novel method.

On the Relationship Between Working and Long-Term Memory

There is an important distinction between the retention of information in short-term versus long-term memory. In the short-term situation, the representation of a studied event can still reside actively within the capacity-constrained working memory system, which many theorists view as residing within activated long-term memory (Cowan, 1988; Oberauer, 2002, 2009) and which may serve as an encoding "bottleneck" for long-term memory (Atkinson & Shiffrin, 1968; Forsberg et al., 2021; Fukuda & Vogel, 2019). The active representation of information in working memory implies that events that still reside within working memory would be more easily accessible and temporally distinctive than those that had been encoded much earlier. In addition, fewer intervening events would have occurred between initial encoding and retrieval, which should minimize the potential for interference to degrade any specific representations that had been formed during encoding. This suggests that short-term retention would be beneficial for retrieving specific memory traces, if ones exist, compared to long-term retention.

Effects of aging on working memory capacity have been widely documented (e.g., Cowan et al., 2006; Greene et al., 2020; Light & Anderson, 1985; Wingfield et al., 1988). Recent research has shown that older adults' working memory capacity limitations can account for their deficits in long-term memory by constraining how much information becomes available in long-term memory (Forsberg et al., under review; but see Bartsch et al., 2019). Given that age-related working memory limitations appear to constrain long-term memory retention and that older adults are less likely to remember episodic associations at specific levels of representation in long-term memory (Greene & Naveh-Benjamin, 2020), it is important to assess whether older adults can initially remember specific details of associations in working memory.

While some studies have shown that age deficits in associative memory appear in working memory (Chen & Naveh-Benjamin, 2012; Kuhlmann et al., 2021), those studies did not attempt to probe the representational quality of associations and whether there are age differences in underlying representations. In these studies, inferences about age deficits were made on the basis of differences in task performance, without appealing to the underlying cognitive mechanisms (such as the specificity of the memory representation) that may have differed between young and older adults. Accordingly, it is unclear whether age deficits in associative memory that occur in the confines of working memory reflect true deficits in the representation of a memory, per se, or if such deficits are attributable to other, nonmnemonic processes, such as age differences in response biases (see Greene & Rhodes, 2022; Salthouse, 2000). Later, we will describe a principled method that will enable us to measure whether there are age differences in specific representations for associations that appear even in working memory. First, however, we consider in more detail what findings of an age deficit in the specificity of associative episodic memory that emerges in working memory, versus one that emerges only in long-term memory, would tell us about older adults' ability to form specific representations in the first place.

Do Older Adults Initially Establish Specific Representations?

Most studies that have examined age differences in the specificity of memories have relied on long-term memory testing, which is less favorable to specific memory traces than short-term testing (Brainerd & Reyna, 2004). It is difficult to determine from these studies whether older adults establish specific representations during initial encoding. Early evidence suggested that older adults encode only semantic aspects of events but do not encode item-specific representations (Hess, 1984; Rabinowitz et al., 1982; Schacter et al., 1998), which is consistent with reports that older adults preferentially rely on a gist-based processing strategy during encoding (Nolte et al., 2022; Tun et al., 1998). Similar evidence has been shown in studies of reading comprehension, in which older adults rely less on representations for the surface form of a passage of text and place more emphasis on situation models (i.e., models that capture the essence, or gist, of a passage of text; Morrow et al., 1992, 1997; Radvansky et al., 2001, 2003; Stine & Wingfield, 1988; Stine-Morrow et al., 2002, 2004; for a review, see Radvansky & Dijkstra, 2007). This line of evidence suggests that older adults are less likely to *encode* specific/verbatim representations, focusing instead on gist or more general representations.

However, it is conceivable that older adults may encode some specific details into memory but fail to access these details later, such as during retrieval from long-term memory. For instance, Jacoby et al. (2005) showed that older adults were less likely to engage in deep elaboration during retrieval, which may be necessary for reintegrating a specific representation of an event (e.g., Brainerd & Reyna, 1990). Similarly, Craik (1983, 1986) has proposed that older adults have problems with self-initiated processing during retrieval, which may impact their ability to access specific, but not gist, details from memory (Craik, 2002). Craik has also proposed that older adults' deficits in episodic memory can be attributable to diminished attentional resources during either encoding or retrieval (Craik & Byrd, 1982; Rabinowitz et al., 1982). Studies employing divided attention manipulations with young adults have been informative to our understanding of the attentional-demanding properties of encoding and retrieval of specific and gist representations. When young adults' attention is divided during encoding, their ability to remember both specific and gist representations of complex associations in episodic memory is diminished (Greene et al., 2022; Greene & Naveh-Benjamin, 2022b). Such deficits are broader than those experienced by older adults, who can remember the gist of associations (Greene & Naveh-Benjamin, 2020). However, a study manipulating divided attention at retrieval produced a more comparable deficit in young adults, restricted only to memory for specific details, that is also observed in older adults (Luo & Craik, 2009).

By probing whether age deficits in specific representations for associations in episodic memory emerge in working memory, we can gain deeper insight into whether older adults could initially form specific representations, given that such testing deconfounds the effects of interference and temporal decay that jointly erode specific memory traces by the time of long-term memory testing. If older adults can remember specific details of associations as well as younger adults during immediate testing, when the representations for the associations can still reside actively in working memory and would have undergone minimal to no interference, but not during long-term testing, then this would show that older adults at least initially encoded specific representations but forgot them by long-term memory testing. Such a finding would be at odds with those in the reading comprehension literature suggesting that older adults rely only on situation models and not on the surface form of text during reading (e.g., Radvansky & Dijkstra, 2007). However, it is possible that retaining the verbatim structure of a passage of text (e.g., the specific way in which a sentence appeared) is not very beneficial, whereas retaining the specific form of a complex episodic association (e.g., remembering specifically where you saw someone) would be beneficial, such that older adults would be more likely to encode such details if they can do so. It is also possible that older adults are less likely to remember specific details of associations even when tests occur within the confines of working memory. In this case, it is possible that older adults failed to form as fully fleshed out specific representations as younger adults, as even when conditions are highly favorable to specific memory traces, age differences in the ability to access such traces would be present.

The Present Study

The purpose of the present study was to determine whether age-related deficits in the ability to remember associations in episodic memory at specific levels of representation observed previously in long-term memory (Greene & Naveh-Benjamin, 2020) would also appear in short-term memory. To do so, we used a continuous associative recognition procedure (e.g., Chen & Naveh-Benjamin, 2012; Hockley, 1992), in which study and test events were presented in a continuous stream. Some test events occur following short delays with as few as zero intervening events between study and test, whereas other test events occur following much longer delays with more intervening events. One early study by Rankin and Kausler (1979) used a continuous recognition procedure to measure age differences in the ability to discriminate previously studied words from related items (synonyms or rhyming words), a discrimination that would be error prone if older adults relied solely on gist memory. Rankin and Kausler (1979) found that older adults made more errors on their task, consistent with an age deficit in memory for specific details. However, the shortest lags (i.e., number of intervening events) in their procedure consisted of eight events, which puts those tests beyond the capacity limits of working memory (e.g., Cowan, 2001). Moreover, Rankin and Kausler (1979) did not present results separately for different lags, so it is unclear from their study whether older adults performed better at shorter compared to longer lags. Finally, Rankin and Kausler (1979) focused on item memory, whereas here we focus on associative memory, given older adults' more pronounced deficits in associative aspects of episodic memory (Naveh-Benjamin, 2000).

Our use of a continuous associative recognition procedure, coupled with a mathematical model (multinomial processing tree [MPT]) for estimating the contributions of specific and gist memory (Stahl & Klauer, 2008), enabled us to determine whether older adults' deficits in specific associative episodic memory emerge in working memory or only in long-term memory. If such deficits occur even on tests of short-term retention, when interference and temporal delay have been minimized, which should be advantageous to specific memory traces if they exist (Brainerd & Reyna, 2002), then older adults likely failed to initially encode specific representations. On the other hand, if older adults can remember specific details to the same extent as young adults on tests of short-term retention, but not so on tests of long-term retention, then older adults clearly at least initially encoded specific representations but were more prone to forgetting them by long-term memory testing.

Method

Transparency and Openness

Links to deidentified data, analysis scripts, and stimuli used in this experiment can be found in the author note. Study design and hypotheses were not preregistered. The experiment was programmed using PsyToolkit software for online data collection (Stoet, 2010, 2017).

Participants

Fifty-three young and 50 older adults participated, but data from three young adults were omitted as the experiment timed out on one participant and two other participants performed below chance level (i.e., < 33% correct) in the short delay trials. This resulted in a final sample size of 50 young adults aged 18–22 ($M = 18.66$, $SD = 1.10$), who were recruited from introductory psychology classes and participated in an online study in exchange for research credits, and 50 older adults aged 65–79 ($M = 69.20$, $SD = 4.01$), who were recruited from the crowd-sourcing platform Prolific (Prolific, n.d.) and participated in exchange for $6.00. Participants were eligible to participate on Prolific if they met the following inclusion criteria based on demographic self-report questions completed on the site (Prolific, n.d.): (a) age between 65 and 80, (b) no self-reported history of dementia or mild cognitive impairment, (c) consumption of no more than 5–9 alcoholic drinks per week, (d) self-reported normal or corrected-to-normal vision, and (e) fluent in English. Demographic measures for the young and old adult samples are presented in Table 1. There was a significant difference in the number of years of formal education, $t(63.75) = -5.01$, $p < .001$, which was higher among older adults than younger adults, but the younger adults were college students who had not yet completed their formal education. Most participants self-identified as female, and there was no significant difference in the proportion of females in each age group, $\chi^2(1) = 0.30$, $p = .584$. Study procedures were approved by the University of Missouri Institutional Review Board, and all participants provided their informed consent prior to participation.

Sample sizes were chosen to match those of Greene et al. (2022), who used a Bayes factor (BF) design analysis (Schönbrodt & Wagenmakers, 2018) based on an estimated effect size of $d = 0.70$ from Greene and Naveh-Benjamin (2020) and an optional stopping rule with a minimum of 30 and a maximum of 60 participants per age group. As we also conducted MPT modeling analyses (see Analyses section), we conducted a Bayesian prior sensitivity analysis for the MPT models. In such a prior sensitivity analysis, we evaluate how informative the data were in determining the values of the posterior distribution of the model parameters by comparing the posterior estimates across models which vary in how much information is conveyed in their prior distributions. Parameter estimates were comparable under both weak and more informed prior specifications (see Supplemental Materials), such that our results are robust across different levels of informativeness of the prior distribution.

Table 1

Demographic Statistics for the Young and Old Adult Samples

Demographic measure	Young adults (n = 50)	Old adults (n = 50)
Age M (SD)	18.66 (1.10)	69.20 (4.01)
YoE M (SD)	12.58 (1.01)	14.75 (1.73)
n females (% of sample)	33 (66%)	29 (58%)
Racial composition	82% Caucasian; 8% Black/ African American; 4% Hispanic; 4% Middle Eastern; 2% multiracial	100% Caucasian

Note. YoE = years of education; M = mean; SD = standard deviation.

Materials and Procedure

We paired pictures of faces from the FACES database (Ebner et al., 2010) with pictures of scenes from a categorized scene pool (Konkle et al., 2010). All faces were White and were evenly divided among young and old and male and female faces, and earlier studies using these types of face stimuli have found no or only small age differences in facial recognition (Brubaker & Naveh-Benjamin, 2018; Chen & Naveh-Benjamin, 2012; Naveh-Benjamin et al., 2004; Peterson et al., 2017). For the scenes, we selected two exemplars from a total of 58 categories (e.g., two parks, two kitchens), with half of the categories depicting outside scenes (e.g., parks, forests, lakes) and half of the categories depicting indoor scenes (e.g., kitchens, dens, offices). There were 116 unique face–scene pairs to be studied, eight of which were presented in a practice phase, while the remaining 108 pairs were presented during the experimental phase.

Participants were instructed that they would be studying face–scene pairs with memory recognition tests appearing at random throughout the experiment. They were informed that the tests would feature three types of test probes that could be categorized as intact (the face appears with the same scene with which the face had been studied), related (the face appears with a scene that is similar to the scene with which the face had been studied), or unrelated (the face appears with a scene that is dissimilar to the scene with which the face had been studied). Following a practice block designed to familiarize participants with the task, participants completed the experimental block, which consisted of 108 study trials and 108 test trials presented in a continuous stream, as illustrated in Figure 1.

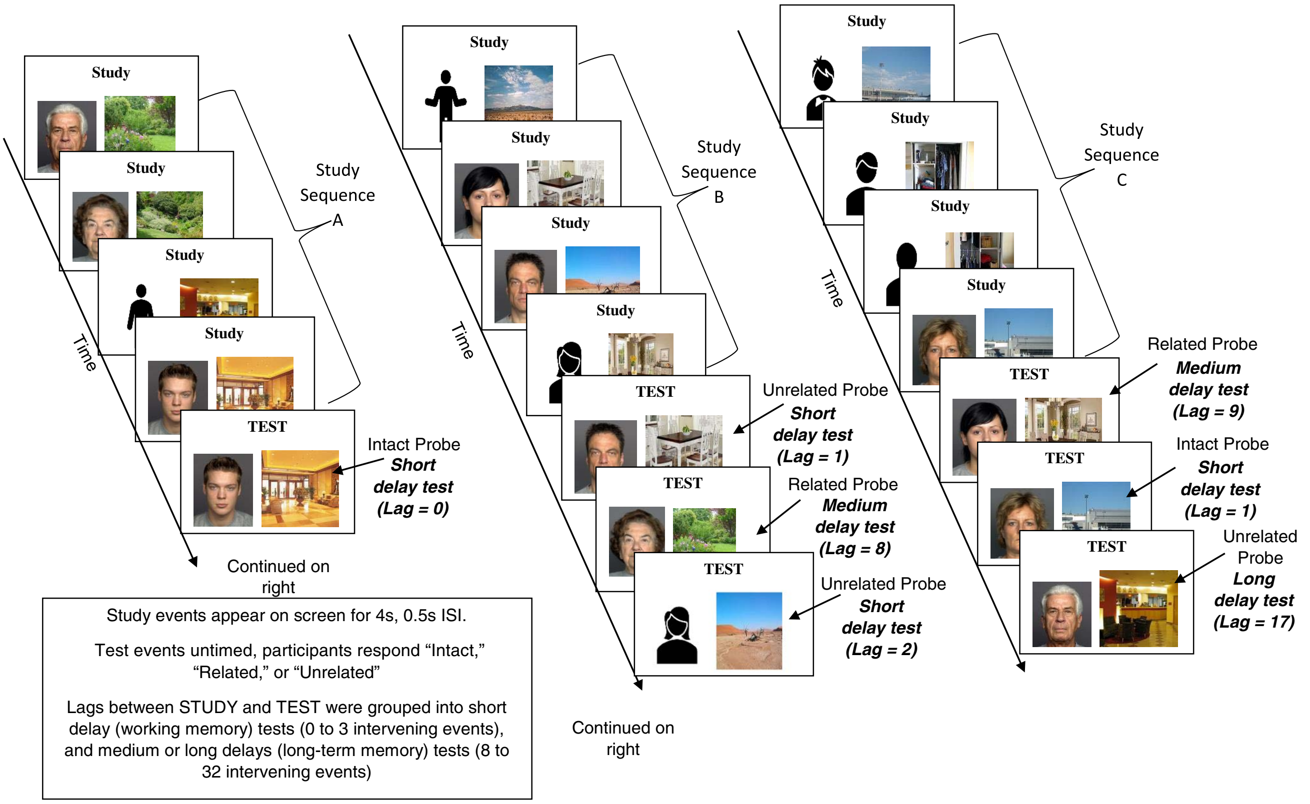
Study Trials

On each study trial, a unique face–scene pair appeared, centered on screen, with the face appearing to the left and the scene to the right, and the word "STUDY" was typed in Size 18 arial font at the top of the display. The pair remained onscreen for 4 s, and a 0.5-s interstimulus interval separated each pair.

Test Trials

On each test trial, a face–scene pair appeared in the center of the screen, as on study trials, but the word "TEST" appeared at the top of the display, with three response options ("Intact," "Related," or "Unrelated") appearing as clickable buttons below the pair. As in standard associative recognition tests, all the faces and scenes that appeared in test trials had previously been studied. However, the pairings between faces and scenes at test were either intact or recombined. For intact pairs, the same face appeared with the same scene with which the face had been studied (e.g., in Figure 1, a young man appears with a lobby at test, and this is the same pairing that had been presented in an earlier study trial). Recombined pairs were constructed by repairing the face from one pair with the scene from another pair. There were two types of recombined pairs which varied in how similar they were to originally studied pairs. Related pairs were similar to studied pairs (e.g., in Figure 1, an old woman appears with a garden during a test trial but had appeared with a *different* garden at study), and unrelated pairs were dissimilar to studied pairs (e.g., in Figure 1, a young man appears with a dining room at test but had appeared with a desert scene during an earlier

Figure 1
Schematic Illustration of Study Procedure



Study events appear on screen for 4s, 0.5s ISI.

Test events untimed, participants respond “Intact,” “Related,” or “Unrelated”

Lags between STUDY and TEST were grouped into short delay (working memory) tests (0 to 3 intervening events), and medium or long delays (long-term memory) tests (8 to 32 intervening events)

Note. Study and test events were presented in a continuous stream, but Study events were always blocked in sequences of four unique pairs (three sequences—Sequence A, Sequence B, and Sequence C—are shown for illustrative purposes). Test events consisted of intact, related, and unrelated pairs. Insert explains whether tests occurred within short-term/working memory or long-term memory, based on the lag (i.e., number of intervening events) between study and test. Lags were based on the number of intervening events between the first presentation of a face (with a scene in a study trial) and the second presentation of that face (with either the same or a different scene in a test trial). Lags were grouped into short delays (0–3 lags), medium delays (8–16 lags), and long delays (17–32 lags); both medium and long delay lags were long-term memory tests. Faces appearing in figure have been approved for display by the authors of the FACES database (Ebner et al., 2010) for purposes of illustrating research methodology. Due to a limited number of faces approved for display, people icons are used as placeholders to represent additional faces. These icons are for illustrative purposes only; participants viewed pictures of faces, not cartoon icons. ISI = interstimulus interval. See the online article for the color version of this figure.

study trial). Participants clicked on one of the three response options (“Intact,” “Related,” or “Unrelated”) appearing below each pair.

Number of Study Trials and Number of Test Trials Appearing Sequentially

Although study and test trials were presented in a continuous stream, study trials occurred in sequences of four pairs, presented one at a time (see Figure 1). This ensured that the two exemplars of a given scene category (e.g., the two dining rooms) appeared at similar times during the experiment such that they would have similar levels of activation in memory by the time of test. If one scene from a given category (e.g., Dining Room 1) appeared, along with its associated face, at a much different time in the experiment than the other scene from that category (e.g., Dining Room 2, along with its associated face), then it is possible that the two scenes would be differentially active in memory at test. For example, imagine the following two pairings appearing during Study Sequence B in Figure 1—the young woman appearing with the first dining room (young woman–Dining Room 1) and the older woman appearing with the second dining room (old woman–Dining Room 2)—occurring during much different times in the experiment (e.g., the two pairs were separated by 15 events, with one pair occurring in Study Sequence A and the other pair occurring in Study Sequence C). If old woman–Dining Room 2 had just been presented at study, and then a related pair was presented immediately at test (old woman–Dining Room 1), the more recently presented Dining Room 2 may still actively reside in working memory, whereas Dining Room 1 would not, due to it having been presented much more distally (e.g., 15 events ago). To avoid this issue, we presented the two exemplars of a given scene category at similar times in the experiment. We also had to ensure that unrelated pairs could be constructed using studied faces and scenes that would have similar levels of activation in memory based on time since study. Thus, study pairs were presented in sequences of four, with all together two scene categories (e.g., dining rooms and deserts, see Study Sequence B in Figure 1), each featuring two unique exemplars, and all the scenes were paired with a unique face (e.g., young woman–Dining Room 1; young man–Desert 1; old man–Desert 2; old woman–Dining Room 2). This made it possible to construct related (e.g., young man–Desert 2) and unrelated (e.g., young man–Dining Room 1) pairs where all the components (the faces and the scenes) would have similar levels of activation in memory. Although test trials occurred after every four study pairs, the number of test trials presented in a row was random, with as few as two test trials and as many as six test trials.

Lags Between Study and Test

The delay between study and test for a given association was based on the number of intervening events (lags) that occurred between the first presentation of a face with a scene during a study trial and the second presentation of that face during a test trial with the same scene (intact pairs) or a different scene (related or unrelated pairs). Lags were grouped into short, medium, and long delays, as depicted in Figure 1. Short delays were between zero and three intervening events, with a median lag of one, such that the pairs tested in the short delays could still reside within the capacity limits of working memory (e.g., Cowan, 2001). Medium delays were between eight and 16 lags (*Mdn* = 12), and long delays were between 17 and 32 lags (*Mdn* = 22). The distinction between medium and long delays was based on the number of intervening study sequences. For a face–scene pair that was presented in one sequence of study events (Study Sequence A), a medium delay test would occur after a second sequence of study events (Study Sequence B), whereas a long delay test would occur after a third sequence of study events (Study Sequence C). Both medium and long delays consisted of enough intervening events (a minimum of 8) that would exceed the capacity limits of working memory and would thus rely on long-term memory instead. There were 12 each of intact, related, and unrelated pairs in the short, medium, and long delays.

Analyses

Analyses were conducted within a Bayesian statistical framework, which confers many advantages over null hypothesis significance testing, especially in studies of cognitive aging, due to the ability to quantify evidence *for* a null effect, which could be informative for adult age comparisons. Differences in response accuracy to each probe in each delay between young and older adults were analyzed with Bayesian analysis of variance (ANOVA), which enabled us to quantify the strength of evidence for or against each main effect and their interactions with BF, where BF_{10} and BF_{01} describe the strength of evidence for an effect or the null, respectively. We also conducted MPT analyses to disentangle the contributions of specific and gist memory representations, thereby going beyond earlier studies that have measured age differences in associative recognition performance in working and long-term memory (e.g., Chen & Naveh-Benjamin, 2012).

Our procedure was based on the simplified conjoint recognition paradigm (Stahl & Klauer, 2008), which enabled us to use an empirically validated MPT model to estimate the contributions of specific and gist memory. MPT models attempt to explain how participants arrive at their responses to a given memory probe by way of unobservable cognitive processes (for reviews, see Batchelder & Riefer, 1999; Erdfelder et al., 2009), but their use in cognitive aging studies has been limited (Greene & Rhodes, 2022). The MPT model from the simplified conjoint recognition paradigm (Stahl & Klauer, 2008) is depicted in Figure 2.

The model has parameters corresponding to specific/verbatim memory (parameters V_i and V_r) and gist memory (parameters G_i and G_r), with the latter being conditional probabilities that participants will still retrieve gist memory upon failing to retrieve specific memory. When participants retrieve gist memory, they must guess whether a probe is “intact” or “related” with probabilities a or $1 - a$, respectively. Participants may sometimes give an “intact” or “related” response to a probe even when they do not access gist memory, and this is modeled via parameter b.

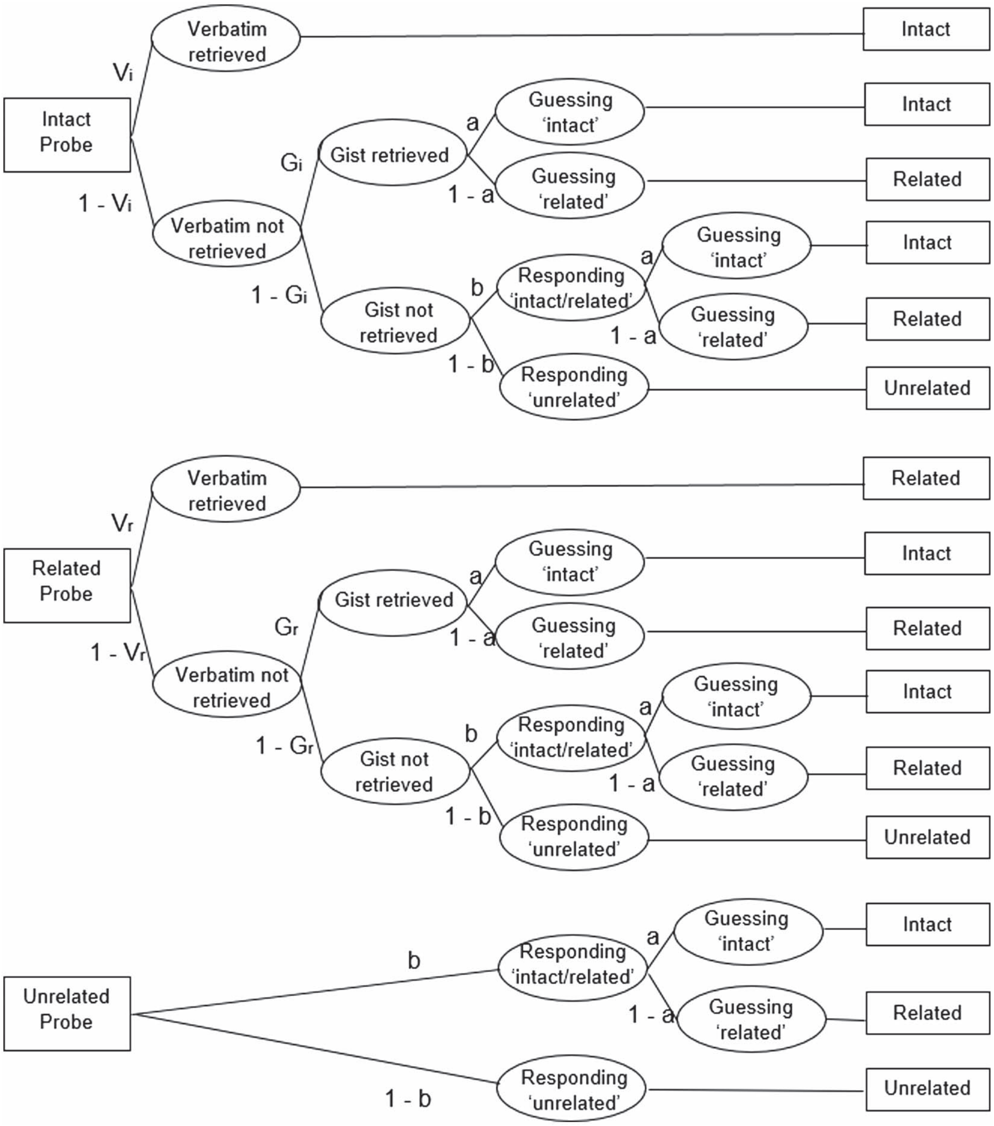
As with any model, the MPT model makes certain simplifying assumptions. One simplification is that there are no specific/verbatim or gist memory parameters for unrelated probes. The technical reason is that, with six parameters corresponding to six degrees of freedom, the model is saturated, so no more parameters could be added without imposing constraints on other parameters. However, including specific and gist parameters for unrelated probes would be redundant with the information already captured in parameter b, as retrieval of any amount of specific or gist detail would be sufficient to reject an unrelated probe. Parameter b indexes the probability that participants will decide to respond “intact” or “related” even when they have not retrieved specific or gist memory, or when the probe does not match specific or gist representations of old pairs (as in the case of unrelated probes). Thus, parameter b captures the probability that a participant will decide, “This *could* be an intact or related probe, even though I do not remember this face being paired with this or a similar scene.” The complementary pathway ($1 - b$, which models correct “unrelated” responses to unrelated probes) indicates that a participant has overcome this bias and will elect instead to respond “unrelated.”

We conducted the MPT analyses using a hierarchical Bayesian latent-trait approach (Klauer, 2010), which allows simultaneous estimation of group- and individual-specific parameters. Models were estimated in the TreeBUGS package in *R* (Heck et al., 2018; R Core Team, 2020), using the program’s default priors. Sampling routine information and modeling diagnostics are available in the Online Supplemental Materials, along with a prior sensitivity analysis.

Under the Bayesian estimation approach, we quantify the *uncertainty* in each parameter within each age group. The uncertainty in a parameter is expressed by the credible interval (CI) of the posterior estimate of a parameter, such that a 95% CI indicates the range in which we can be 95% certain the true value of the parameter lies. This is different from a frequentist confidence interval, which does not provide us with probability statements about the true value of a parameter and is predicated instead on repeat sampling from a population (Kruschke, 2011). We can also compare parameters between young and older adults seamlessly under the Bayesian framework. To do so, we computed difference scores for each parameter by subtracting the posterior distributions of the older adults’ model from the younger adults’ model. This resulted in a posterior mean difference and 95% CI, conveying the range in which we can be 95% sure that the true difference lies. We used a simple decision rule based on recommendations from Smith and Batchelder (2010) to determine whether there was credible evidence for an age difference in each parameter. Specifically, if the 95% CI of the difference score for a given parameter excluded 0, we

Figure 2

Simplified Conjoint Recognition Multinomial Processing Tree (MPT) Model



Note. Model is used for estimating the contributions of specific/verbatim and gist memory. Memory probes (intact, related, and unrelated) are presented as boxes on the left; the presentation of a given memory probe activates cognitive processes, which are depicted in a branch-like structure for each probe, culminating in one of the three possible response options in the boxes on the right. Parameters represent the probability of a given process occurring. Parameters V_i and V_r denote the probability of verbatim retrieval given an intact or a related probe, respectively. Parameters G_i and G_r denote the conditional probability of gist retrieval, when participants fail to retrieve verbatim memory, given an intact or a related probe, respectively. Parameter a denotes the probability of guessing "intact." Parameter b denotes the probability of responding either "intact" or "related."

concluded there was credible evidence for an age difference for a given parameter because we can be 95% certain that there was a nonzero difference. Otherwise, if the 95% CI of the difference score for a given parameter included 0, we remained agnostic, meaning we could not rule out the possibility that there was no difference in the parameter between young and older adults. Because we based our conclusions about the presence of an age difference on whether 0 was excluded from the 95% CI, we were able to get more traction on the *strength* of evidence for or against the point null by computing BF using the Savage–Dickey method (Wagenmakers et al., 2010). Technical details of the method are provided in the Online Supplemental Materials, but in essence, this method enabled us to compare the posterior density of a slope for age group on a given parameter at 0 to the prior density of that slope at 0. If the posterior density has moved *away* from 0, then this provides evidence against the null effect of age, whereas if the posterior density is more concentrated at 0 than the prior density was, then this provides evidence *for* the null effect of age.

Results

Memory Accuracy Results

The proportion of correct responses to all probes in each delay for young and older adults is depicted in Figure 3. Table 2 gives the mean proportions of all responses to each probe. We conducted a 2 (age) × 3 (probe) × 3 (delay) mixed Bayesian ANOVA on the proportion of correct responses, using the default prior options in JASP (JASP Team, 2020) which follow recommendations from Rouder et al. (2012). There was overwhelming evidence for all main effects, all $\text{BF}_{10} \geq 9.36 \times 10^6$. There was also overwhelming evidence for the Age × Probe interaction ($\text{BF}_{10} = 6.64 \times 10^4$) and for the Probe × Delay interaction ($\text{BF}_{10} = 4.51 \times 10^{11}$) and moderate evidence for the Age × Delay interaction ($\text{BF}_{10} = 8.17$). However, the evidence for the triple interaction of age, probe, and delay was only weak but positive ($\text{BF}_{10} = 1.25$).

The main effect of age was characterized by lower accuracy among older adults than young adults. For the effect of delay, accuracy declined from short to medium delays ($\text{BF}_{10} = 3.24 \times 10^{18}$) but did not differ between medium and long delays ($\text{BF}_{01} = 4.35$). For the effect of probe, accuracy differed among all probes (all $\text{BF}_{10} \geq 1.31 \times 10^4$), being highest for unrelated probes and lowest for related probes. However, these main effects need to be considered in light of the credible interactions. For the Age × Probe interaction, the effect of age (young > old adults) held for intact probes ($\text{BF}_{10} = 11.86$) and related probes ($\text{BF}_{10} = 1.63 \times 10^4$), but the evidence was more in favor of a null effect of age for unrelated probes ($\text{BF}_{01} = 1.25$).

For the Age × Delay interaction, there were credible age differences in each delay (short: $\text{BF}_{10} = 2.20$; medium: $\text{BF}_{10} = 1.10 \times 10^3$; long: $\text{BF}_{10} = 779.67$), but the evidence in the short delay is weak (e.g., van Doorn et al., 2021). As depicted in Figure 3, there appears to be more separation in the means of the young and older adults for related probes in the short delay than for either intact or unrelated probes. Consistent with this visual impression, when we restricted our analyses to examine age differences in the short delay to each probe separately, there was strong evidence for an age difference on related probes ($\text{BF}_{10} = 36.26$) but the null was favored for both intact ($\text{BF}_{01} = 2.50$) and unrelated ($\text{BF}_{01} = 4.54$) probes.[1]

Finally, for the Probe × Delay interaction, the main effects of delay described previously (short > medium = long) held for intact and unrelated probes, though in the latter case, while there was a decline from short to medium delay, there was no credible difference between short and long delays ($\text{BF}_{01} = 2.17$).[2] For related probes, accuracy also declined from medium to long delays ($\text{BF}_{10} = 34.19$).

To summarize, younger adults outperformed older adults on most probes and in each delay, with a few important exceptions. First, older adults performed equally well as younger adults at correctly rejecting unrelated probes. Second, older adults did not credibly differ from younger adults at correctly identifying intact probes in the short delays. In addition, response accuracy declined from short to medium delays but remained stable from medium to long delays, except for to related probes, for which accuracy also declined from medium to long delays.

MPT Results

To ensure that the MPT models captured the patterns of responses in the data, we computed posterior predictive checks, in which the posterior distributions of the model parameters were used to simulate 1,000 new datasets. Then, the correspondence between the posterior-predicted and observed means and covariances was computed via the T_1 and T_2 statistics, respectively (Klauer, 2010). A posterior predictive p (PPP) value was computed for each statistic. Model fit is considered satisfactory when PPP > .05. In most cases, model fit was satisfactory, with PPP ≥ .22 for all T_1 and T_2 statistics, with one exception. The model predicted that older adults would make more correct "related" responses and fewer incorrect "intact" responses to related probes in the longest delays compared with the observed rates of "related" and "intact" responses in the data. This amounted to a misfit of the model to the older adults' data in the long delay, with PPP = .002 for the T_1 statistic. A plausible reason for this is that the model estimated that older adults never retrieved specific memory when shown a related probe (parameter V_r) in the long delays, with an estimated mean parameter value of 0.01. Therefore, we constrained parameter Vr in the long delay to equal the mean value of this parameter in the medium delay among older adults, and we introduced another guessing parameter (a_b), modeling a different proclivity to guess "intact" in cognitive state b (see Greene & Naveh-Benjamin, 2020). This additional parameter captures the possibility that older adults were less likely to guess "intact" when in cognitive state b (where neither specific nor gist memory was remembered) than they were when they retrieved gist memory. This modified model satisfactorily captured the patterns of responses in the data, with PPP = .51 for the T_1 statistic, and did not alter the posterior estimates of the memory parameters.

Population-level parameter estimates are listed in Table 3, and Figure 4 depicts the posterior distribution of each parameter for a visual comparison of the amount of overlap for each parameter from the young and older adults' models. Difference scores obtained by subtracting the posterior samples of the older adults from the younger adults are given in the last column of Table 3.

In the short delay tests (see Figure 4A), occurring within working memory, the only credible age difference was in the probability of retrieving specific memory when the test probe was a related probe, that is, parameter V_r, which was higher in younger adults. The BF derived from the Savage–Dickey method was in favor of an age difference, $\text{BF}_{10} = 3.70$. However, older adults were as capable as younger adults at retrieving specific memory when shown an intact probe (parameter V_i), $\text{BF}_{01} = 3.33$, and both young and older adults were equally capable of retrieving gist memory, with $\text{BF}_{01} = 6.25$ and 11.11 for age differences in parameters G_i and G_r, respectively. Young and older adults were equally like to guess "intact" rather than "related" (parameter a), $\text{BF}_{01} = 14.29$, and there were no age differences in the proclivity to respond either "intact" or "related" (parameter b), $\text{BF}_{01} = 14.29$.

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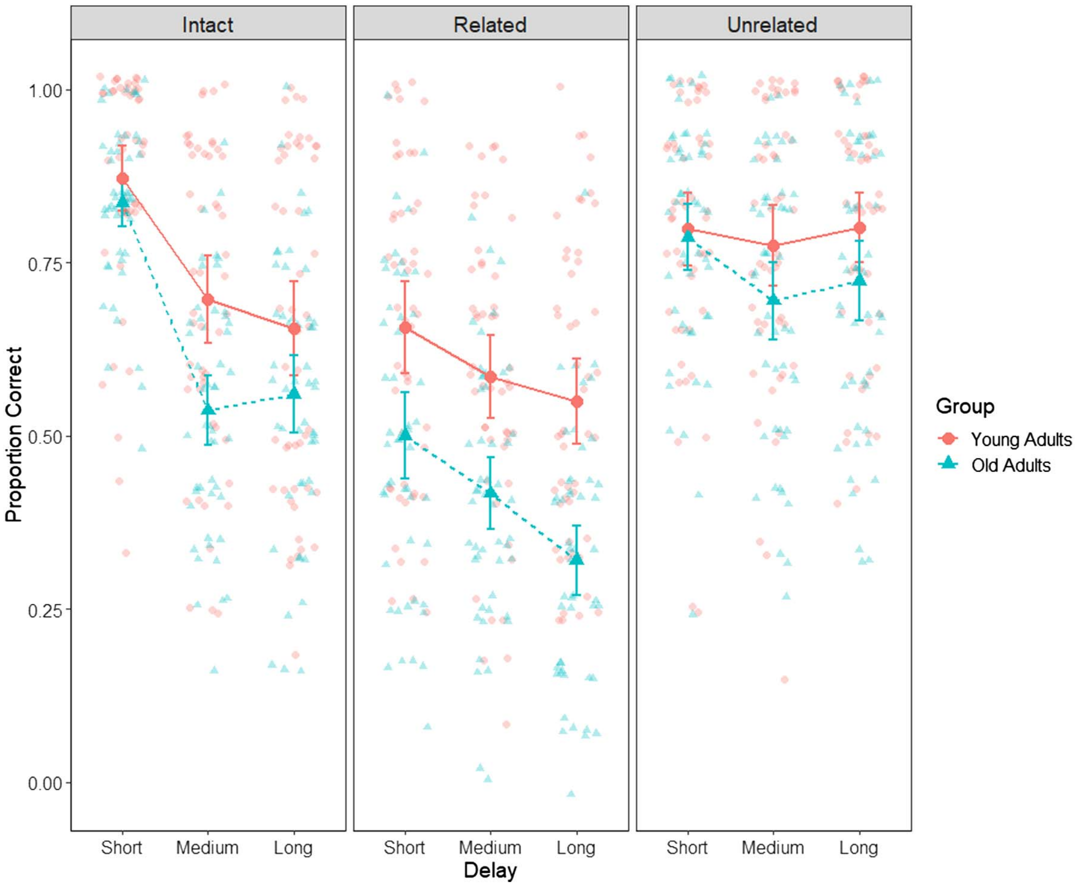
[1] This is consistent with the overall finding of weak, but positive, evidence in favor of a triple interaction term. While follow-up tests on an inconclusive interaction term may seem unjustified, there are a priori reasons for expecting there to be age differences on related (and possibly intact) but not unrelated probes, as such predictions are based on evidence from Greene and Naveh-Benjamin (2020).

[2] That is, for unrelated probes, there was a slight dip in performance from short to medium delay, but accuracy "re-stabilized" in long delays to be on par with accuracy in the short delays. This did not occur for intact probes, where accuracy in long delays was lower than accuracy in the short delays.

Figure 3

Proportion Correct for Each Probe as a Function of Age and Delay



Note. Error bars are 95% confidence intervals. Jittered points and triangles are individual participants' data. See the online article for the color version of this figure.

In the medium delay tests (see Figure 4B), older adults were less likely to retrieve specific memory when shown an intact probe, such that there was a credible age difference in parameter V_i, $BF_{10} = 1.40 \times 10^3$. The age difference in parameter V_r was no longer credible, $BF_{01} = 2.09$. There were no age differences in the gist memory parameters, with $BF_{01} = 14.29$ and 9.09 for G_i and G_r, respectively. However, older adults had a slightly greater tendency to guess "intact" (parameter a), $BF_{10} = 3.56$. Also, older adults were slightly more likely to respond either "intact" or "related" (parameter b), $BF_{10} = 1.49$, though this evidence is weak.

Age-related differences in parameter estimates in the long delay (see Figure 4C) closely mirror those from the medium delay. However, we were unable to estimate parameter V_r among older adults, as this parameter was essentially 0, which prevented us from estimating age differences in the slope of each parameter necessary to compute BFs. Nevertheless, the difference score in parameter V_i was similar in

Table 2

Proportion of "Intact," "Related," and "Unrelated" Responses by Young and Older Adults to All Probes in Each Delay

	Intact probes			Related probes			Unrelated probes		
Age by delay	"Intact"	"Related"	"Unrelated"	"Intact"	"Related"	"Unrelated"	"Intact"	"Related"	"Unrelated"
YA short	.87 (.02)	.08 (.01)	.05 (.01)	.25 (.03)	.66 (.03)	.09 (.01)	.10 (.02)	.10 (.02)	.80 (.03)
OA short	.84 (.02)	.11 (.01)	.06 (.01)	.40 (.03)	.50 (.03)	.10 (.02)	.10 (.02)	.11 (.02)	.79 (.02)
YA med	.70 (.03)	.16 (.03)	.15 (.02)	.23 (.02)	.59 (.03)	.19 (.02)	.09 (.02)	.14 (.02)	.78 (.03)
OA med	.54 (.02)	.23 (.02)	.24 (.02)	.38 (.02)	.42 (.03)	.21 (.02)	.15 (.02)	.16 (.02)	.70 (.03)
YA long	.66 (.03)	.15 (.02)	.19 (.02)	.19 (.02)	.55 (.03)	.26 (.02)	.07 (.01)	.13 (.02)	.80 (.02)
OA long	.56 (.03)	.21 (.02)	.23 (.03)	.35 (.03)	.32 (.03)	.33 (.03)	.11 (.02)	.17 (.02)	.72 (.03)

Note. Values are mean (*SE*). OA = old adult; YA = young adult; Med = medium delay.

Table 3

Population-Level Parameter Estimates [95% Credible Intervals] of the MPT Model Across Short, Medium, and Long Lags

Parameter	YA	OA	Difference (YA–OA)
V_i (short)	0.84 [0.75, 0.92]	0.74 [0.66, 0.80]	0.10 [−0.01, 0.21]
V_r (short)	0.33 [0.12, 0.52]	0.05 [0.00, 0.15]	**0.29 [0.05, 0.49]**
G_i (short)	0.84 [0.59, 0.99]	0.76 [0.63, 0.88]	0.08 [−0.21, 0.30]
G_r (short)	0.81 [0.73, 0.89]	0.88 [0.82, 0.93]	−0.06 [−0.16, 0.04]
a (short)	0.52 [0.42, 0.64]	0.47 [0.38, 0.57]	0.05 [−0.09, 0.20]
b (short)	0.18 [0.12, 0.24]	0.19 [0.14, 0.25]	−0.02 [−0.10, 0.06]
V_i (medium)	0.61 [0.49, 0.71]	0.27 [0.14, 0.37]	**0.34 [0.18, 0.51]**
V_r (medium)	0.15 [0.01, 0.33]	0.05 [0.00, 0.13]	0.11 [−0.06, 0.30]
G_i (medium)	0.50 [0.36, 0.62]	0.52 [0.42, 0.61]	−0.02 [−0.18, 0.14]
G_r (medium)	0.70 [0.58, 0.80]	0.67 [0.59, 0.74]	0.03 [−0.11, 0.16]
a (medium)	0.37 [0.27, 0.49]	0.51 [0.44, 0.58]	**−0.14 [−0.26, −0.01]**
b (medium)	0.19 [0.13, 0.25]	0.29 [0.23, 0.35]	**−0.10 [−0.19, −0.02]**
V_i (long)	0.56 [0.42, 0.69]	0.26 [0.09, 0.40]	**0.31 [0.10, 0.52]**
V_r (long)	0.14 [0.01, 0.31]	—	—
G_i (long)	0.43 [0.30, 0.56]	0.52 [0.33, 0.67]	−0.09 [−0.29, 0.14]
G_r (long)	0.59 [0.46, 0.70]	0.52 [0.41, 0.61]	0.07 [−0.09, 0.23]
a (long)	0.35 [0.25, 0.46]	0.63 [0.52, 0.74]	**−0.28 [−0.43, −0.13]**
b (long)	0.17 [0.12, 0.23]	0.25 [0.19, 0.32]	−0.08 [−0.16, 0.00]
a_b (long)	—	0.32 [0.20, 0.44]	—

Note. OA = old adult; YA = young adult; MPT = multinomial processing tree. Bolded difference scores exclude 0 from the 95% credible interval. V_i = probability of verbatim retrieval given an intact probe; V_r = probability of verbatim retrieval given a related probe; G_i = probability of gist retrieval given an intact probe; G_r = probability of gist retrieval given a related probe; a = probability of guessing "intact" when gist is retrieved; b = probability of guessing "intact/related" when there is no verbatim or gist information; a_b = proclivity to guess "intact" in cognitive state b. Age differences in specific retrieval of related probes (parameter V_r) could not be assessed in the long delays because the MPT model could not estimate this parameter for older adults in the long delays. This essentially suggests this parameter was 0 (i.e., older adults *never* retrieved verbatim memory when shown a related probe in the long delays, and their responses were entirely based on gist memory and guessing).

magnitude to the difference in this parameter in the medium delay (see Table 3), indicating that younger adults were more capable than older adults of retrieving specific memory when shown intact probes. The difference scores for parameters G_i and G_r were similar in the long and medium delays (see Table 3), and 0 was contained within the 95% CI of the difference scores in the long delay, such that there was no evidence for a credible age difference in the gist memory parameters.

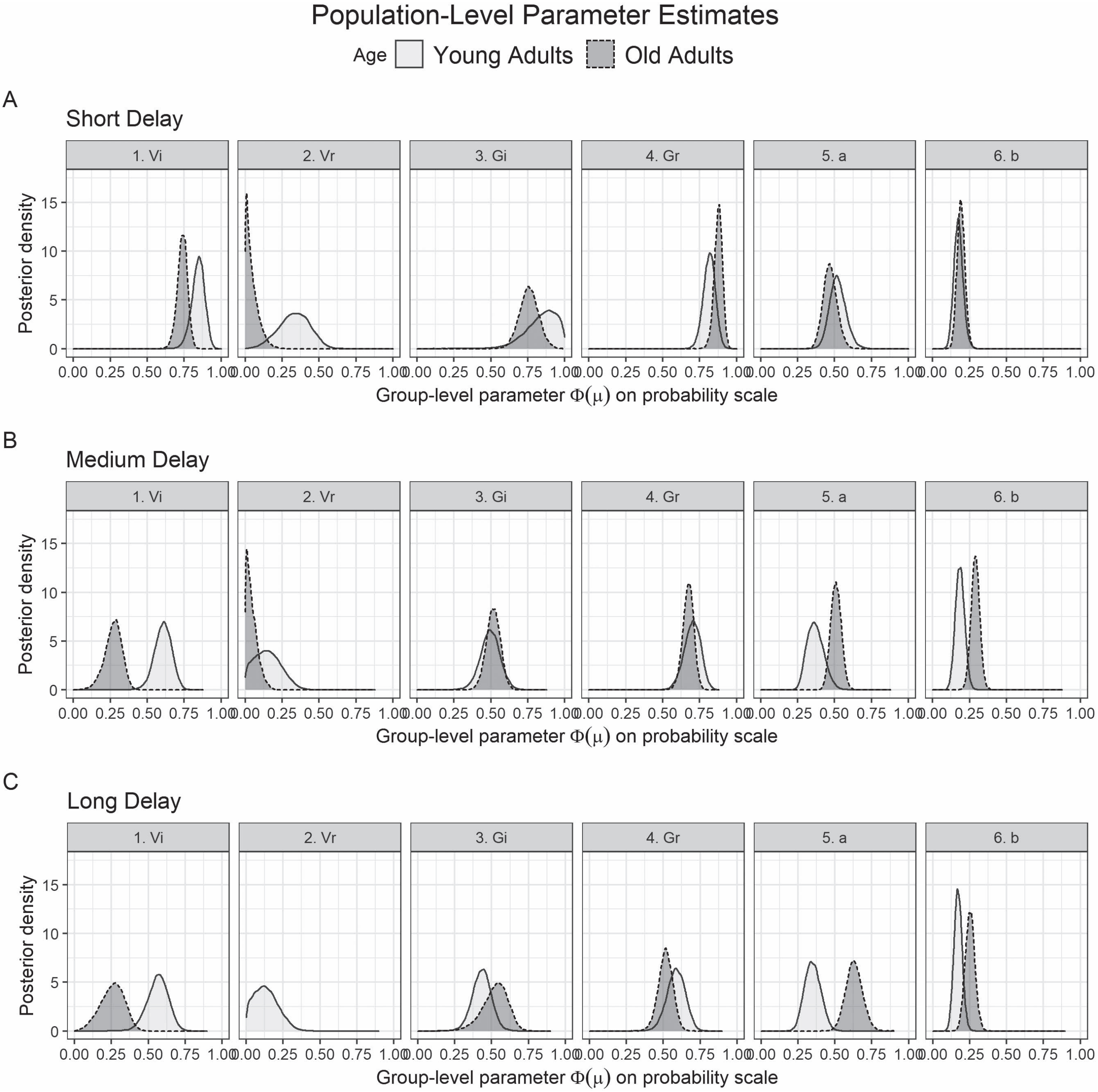
The MPT results demonstrated age deficits in at least one specific memory parameter in each delay, while gist memory parameters did not differ between age groups in any delay. In the shortest delays, the age differences in specific memory were present for related probes, as younger adults were more capable of retrieving specific memory and engaging in recollection rejection (i.e., rejecting related probes based on their mismatch with originally studied information) than older adults were. However, age differences in specific retrieval when presented related probes no longer held in medium delays, but instead, older adults were less capable of retrieving specific memory when shown intact probes. This was manifest by a steeper decline in parameter V_i from short to medium delay among older adults than younger adults (see Figure 5).

There are a few noteworthy aspects of Figure 5. In both age groups, there was a decline in parameter V_i from short to medium delays, ΔV_i(short–medium) = 0.24, 95% CI [0.09, 0.38] for young adults and ΔV_i(short–medium) = 0.47, 95% CI [0.34, 0.61] for older adults, but no further credible decline from medium to long delays (in both age groups, the 95% CI for ΔV_i(medium–long) encompassed 0). There were no credible delay differences for parameter V_r from short to medium nor from medium to long delay in young adults, nor a credible difference from short to medium delay in older adults (all 95% CIs of the difference scores contained 0). However, it is worth noting that, among older adults, estimates of V_r were nearly indistinguishable from 0 even in short-term memory, such that older adults almost never retrieved specific memory when shown related test probes. For the gist memory parameters, there were similar delay effects on parameter G_i in both groups, with a decline from short to medium delay, ΔG_i(short–medium) = 0.34, 95% CI [0.06, 0.56] for young adults and ΔG_i(short–medium) = 0.24, 95% CI [0.08, 0.40] for old adults, but no further decline from medium to long delay (i.e., 0 was contained within the 95% CI for ΔG_i(medium–long) in both groups). However, while the overall pattern in the change in parameter G_r from short to medium to long delay was similar in both age groups (see Figure 5), among young adults, the difference from short to medium delays did not credibly differ from 0, nor did the difference from medium to long delay, but there was a credible difference between short and long delays, ΔG_r(short–long) = 0.23, 95% CI [0.09, 0.37]. Among older adults, this difference occurred sooner, between short and medium delays, ΔG_r(short–medium) = 0.20, 95% CI [0.11, 0.30], and estimates of G_r continued to decline between medium and long delays, ΔG_r(medium–long) = 0.16, 95% CI [0.04, 0.28].

The delay effects on the specific and gist memory parameters show a quick rate of decline in specific memory from short-term to long-term memory, which is consistent with fuzzy-trace theory (e.g., Brainerd & Reyna, 2002). However, gist memory also declined from short-term to long-term memory, though there were some age-related differences in the rate of this decline, which occurred more immediately for older adults than younger adults.

Figure 4

Posterior Distributions of the Group-Level Parameters of the Simplified Conjoint Recognition MPT Model



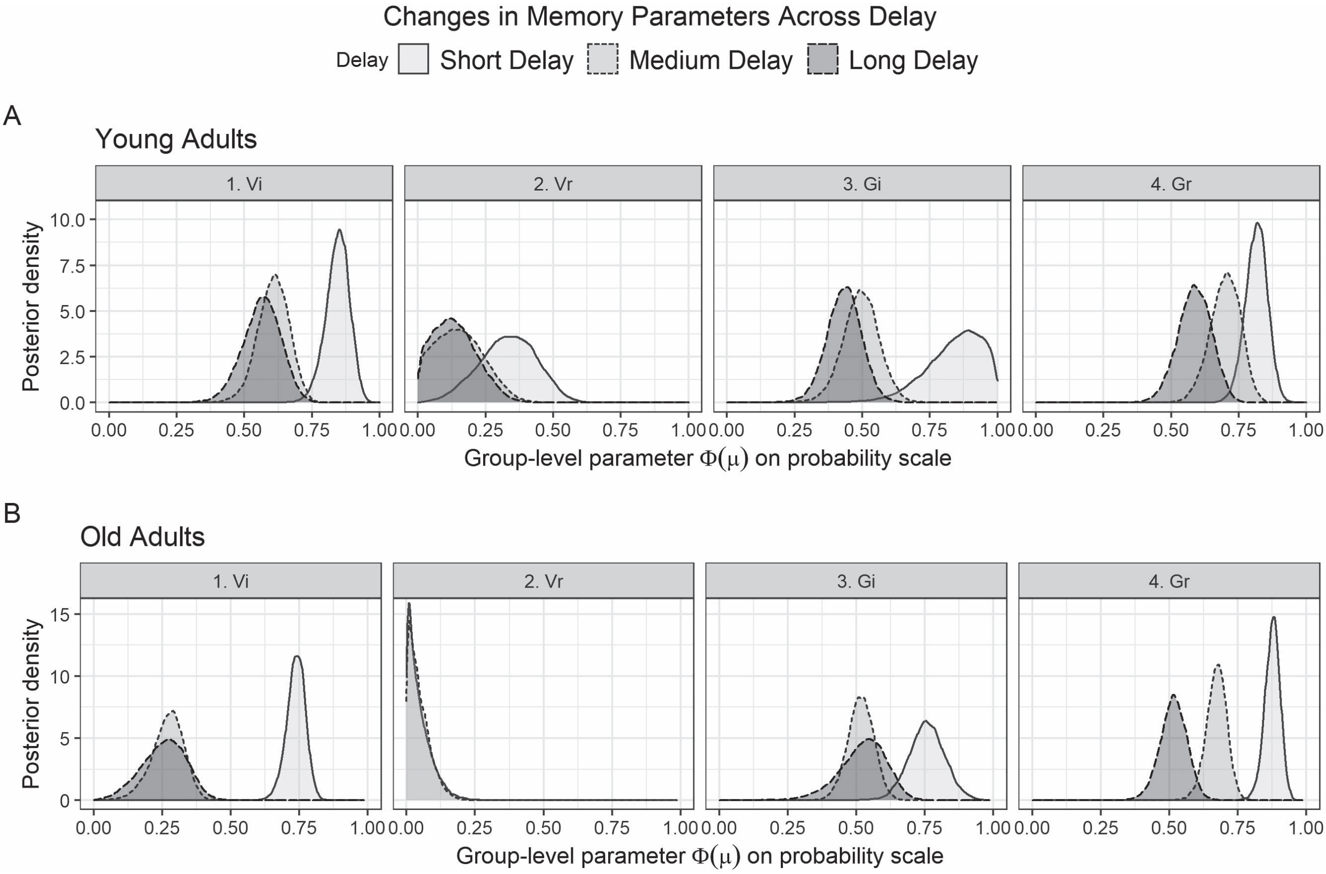
Note. MPT = multinomial processing tree. Group-level parameters have been inverse-probit transformed to appear on the probability scale. Posterior distributions are shown for the short delay (A), medium delay (B), and long delay (C), for the memory parameters V_i (probability of specific/verbatim retrieval given an intact probe), V_r (probability of specific/verbatim retrieval given a related probe), G_i (probability of gist retrieval given an intact probe), and G_r (probability of gist retrieval given a related probe), and the response bias parameters *a* (guessing "intact") and *b* (responding either "intact" or "related").

Discussion

A ubiquitous hallmark of normal aging is a decline in the efficiency of episodic memory (Naveh-Benjamin & Old, 2008; Zacks et al., 2000). Older adults are especially prone to forgetting associations between components of an episode (Naveh-Benjamin, 2000), which are core to episodic memory (Zimmer et al., 2006). While such age-related deficits in the associative aspects of episodic memory have been widely reported in the literature (Old & Naveh-Benjamin, 2008), recent research has suggested that these deficits are most prominent for remembering associations at specific levels of representation (Greene & Naveh-Benjamin, 2020; and see Castel, 2005). Such

Figure 5

Changes in Memory Parameters Across Delay for Young and Older Adults



Note. Posterior distributions are for group-level parameters, which have been inverse-probit transformed to the probability scale, and appear for young adults (A) and old adults (B). V_i = probability of verbatim/specific memory retrieval when shown an intact probe; V_r = probability of verbatim/specific memory retrieval when shown a related probe; G_i = probability of gist memory retrieval when shown an intact probe; G_r = probability of gist memory retrieval when shown a related probe.

findings are in accord with a larger body of evidence showing that older adults are capable of remembering the gist of episodes but are impaired in their memory for specific details (Castel et al., 2007; Greene et al., 2022; Greene & Naveh-Benjamin, 2020; Koutstaal, 2003; Koutstaal et al., 1999; Kensinger & Schacter, 1999; Koutstaal & Schacter, 1997; Luo & Craik, 2009; Morrow et al., 1992, 1997; Radvansky & Dijkstra, 2007; Radvansky et al., 2001, 2003; Rankin & Kausler, 1979; Reder et al., 1986; Schacter et al., 1997; Simons et al., 2004; Stark et al., 2013; Stine & Wingfield, 1988; Stine-Morrow et al., 2002, 2004; Tun et al., 1998).

We attempted to determine when age-related deficits in memory for associations at specific levels of representation emerge. Specifically, we assessed whether these deficits occurred in working memory in addition to long-term memory, where the evidence for age-related deficits in memory for specific details has traditionally been reported (Greene & Naveh-Benjamin, 2020; Greene et al., 2022). A potential confound of comparing older adults' abilities to remember specific details with those of younger adults on long-term memory tests is that specific/verbatim memory traces are highly susceptible to degradation across time and due to interference (Brainerd & Reyna, 1990, 2002, 2004). Thus, even if older adults in many of the earlier studies were able to initially establish a specific representation as well as younger adults, they may have forgotten that specific representation by the time of long-term memory testing, given older adults' heightened susceptibility to interference (e.g., Hasher & Zacks, 1988). In contrast, in working memory, with minimal to no interference between encoding and retrieval, specific memory traces would be less likely to have disintegrated. Therefore, if older adults can remember specific details of associations on short-term memory tests, but fail to do so in long-term memory, then it would appear that older adults initially encode specific details but forget such details by the time of long-term memory testing.

On working memory tests of our continuous recognition procedure, we found that older adults could sometimes remember specific details as well as younger adults. Older adults were equally capable as younger adults at retrieving specific memory when shown intact test pairs (i.e., the same face appearing with the same scene with which the face had been studied) following a short delay of zero to three intervening events. However, older adults were less capable than younger adults at retrieving specific memory when shown a related test pair (i.e., the same face now appears with a similar, but different, scene than the scene with which the face had appeared earlier, such as young man—Park 1 at study vs. young man—Park 2 at test) following a short delay. When tests occurred following longer delays, beyond the capacity limits of working memory, older adults were deficient in retrieving specific memory representations when shown intact pairs, and they essentially never retrieved specific representations when shown related pairs, responding instead on the basis of gist memory and guessing strategies. However, older adults were always equally capable as younger adults at remembering gist details of associations. These results were borne out of an MPT analysis (Stahl & Klauer, 2008) which enabled us to estimate the contributions of specific and gist memory more precisely than in most previous aging studies. The MPT results showed credible age differences (young > old adults) in a specific/verbatim memory parameter corresponding to the probability of retrieving specific memory representations when shown related probes in working memory tests. In long-term memory tests, parameter estimates for specific/verbatim memory retrieval when shown intact probes were higher for young than older adults. However, in both working and long-term memory tests, parameters corresponding to the probability of retrieving gist representations did not credibly differ between young and older adults. In what follows, we explain how the present set of findings inform our collective understanding of age-related effects on specific memory, especially for the associative aspects of an episode.

Can Older Adults Initially Encode Specific Details to Comparable Extents as Younger Adults?

The finding that older adults were as capable as younger adults at accessing specific representations for intact probes in short-term tests suggests that older adults were able to encode specific memories initially as well as younger adults. Such a finding is at odds with research suggesting that older adults encode semantic, gist-based details with less focus on specific details (e.g., Hess, 1984; Rabinowitz et al., 1982; Schacter et al., 1998; Tun et al., 1998) and those in the reading comprehension literature showing that older adults do not process the surface form of a passage of text, focusing instead on the essence (i.e., gist) of the text (see Radvansky & Dijkstra, 2007). However, the present study suggests that even if older adults do initially establish specific representations for complex associations, such that these representations can be relied upon in working memory testing, the extent to which older adults can access these specific representations is cue dependent. In particular, older adults were as capable as younger adults of accessing specific representations of an originally studied face–scene pair when that pair was re-presented at test (i.e., as an intact pair) and the test occurred almost immediately after encoding, within the confines of working memory. However, older adults were less capable than younger adults of accessing specific representations of an originally studied face–scene pair when the pair presented at test in the short-term testing situation was *similar* but not identical to the originally studied pair.

This finding implicates encoding specificity (Tulving & Thomson, 1973) and the correspondence between encoding and retrieval conditions (Surprenant & Neath, 2009) as an important determinant of whether older adults will show deficits in the ability to remember specific details in short-term memory. In accord with the encoding-specificity principle, a test probe that reinstantiates more of the original encoding context will serve as a better retrieval cue for item-specific information. In other words, intact test pairs are better retrieval cues for specific traces than related pairs are (cf. Brainerd et al., 2019; Brainerd & Reyna, 1990). Indeed, evidence from the changes in specific memory parameters across delays in the present study is consistent with this interpretation. Notably, participants were far less likely to retrieve specific details when shown a related pair than when shown an intact pair, and this was true of both young and older adults. Moreover, estimates of specific retrieval when participants were shown related pairs were nearly indistinguishable from 0 in long-term retention situations, especially among older adults.

Because related pairs are less effective cues for retrieving specific memory traces, it is likely that further self-initiated processes may be necessary for retrieving specific memory when shown related pairs. This is because for related pairs, verbatim/specific and gist traces can support opposing outcomes (Brainerd et al., 1999, 2019); specific traces support a rejection response, while gist traces can support an acceptance response. Thus, disentangling these two outcomes may require more self-initiated processing during retrieval, and theories of cognitive aging suggest that older adults are less likely to engage in self-initiated processing (Craik, 1983, 1986), which may partially explain why older adults do worse on tests of recall than recognition (Danckert & Craik, 2013; Rhodes et al., 2019) and on tests of associative than item recognition (Old & Naveh-Benjamin, 2008). Accordingly, older adults' deficits in remembering specific details when shown related pairs on short-term tests in the present study may reflect issues with deep elaboration during retrieval (e.g., Jacoby et al., 2005). Over longer delays in the present study, older adults' deficits in remembering specific details when shown intact pairs could also be consistent with a failure of deep elaboration at retrieval, in that with more interference from intervening events, specific memory traces would likely have disintegrated more on long-term than short-term tests (Brainerd & Reyna, 2002), such that more effort may be needed to reintegrate specific representations even when the test probe perfectly matches the studied conditions (i.e., in the case of intact pairs).

Limitations

The present study is not without its limitation. The discrete-state assumption implied by MPT models, like the simplified conjoint recognition model (Stahl & Klauer, 2008) employed here, has been the subject of some controversy (Batchelder & Alexander, 2013; Dube & Rotello, 2012; Klauer & Kellen, 2011a, 2011b; Pazzaglia et al., 2013; Province & Rouder, 2012). Nevertheless, the MPT model used here appears to be a reasonable tool for estimating the contributions of specific and gist memory, as it has been empirically validated, such that its parameters have been shown to correspond to manipulations that would produce expected changes in specific or gist memory (Stahl & Klauer, 2008). Moreover, the controversy surrounding MPT models has been restricted to studies of item rather than associative recognition; in the latter case, MPT models may offer a better account of the data (Yonelinas, 1997). Also, the use of cognitive models in cognitive aging research has been scarce (see Greene & Rhodes, 2022). Our use of an MPT model to estimate the contributions of specific and gist memory in the present study provides more meaningful information about these memory states than almost all studies that have attempted to measure age differences in memory specificity, as most previous studies have focused solely on analyses on the observed behavioral data (i.e., with ANOVA-based approaches), which cannot determine which cognitive processes are affected (Salthouse, 2000).

Another potential limitation of the present study is the extent to which our findings would generalize to more diverse samples. We recruited older adults online using the crowdsourcing platform Prolific. However, many questions still remain about the diversity of older adults who participate in online studies (Greene & Naveh-Benjamin, 2022a). Indeed, in the present study, the older adults all identified as White, so we cannot ascertain whether similar patterns of results would be obtained with older adults of different races. It is worth noting that our younger adult sample was also majority-White, but we were able to examine whether there were differences in younger adults' performance on the task as a function of participant race and we found no such differences (see Online Supplemental Materials). In a similar vein, all the faces used as stimuli in the present study were White, which could limit the generalizability of these findings to more naturalistic settings in which people encounter more ethnically diverse faces. Replication of this work using a more diverse stimulus set would be a desirable avenue for future research.

We designed our short-term tests to occur almost immediately after study, within zero to three intervening events, as such test conditions should be favorable to specific memory traces (e.g., Brainerd & Reyna, 2002). At the same time, this may have made the short-term tests much easier than in standard associative recognition tasks, as evident by high accuracy to both intact and unrelated probes in the short delay tests (see Figure 3), with many young and older adult participants performing exceptionally well (nearly 100% correct) at classifying these probes when the tests occurred almost immediately after encoding. For the purpose of assessing whether older adults can initially establish specific representations as well as younger adults, high levels of performance in these potentially easier conditions would seem desirable, inasmuch as these trials were designed to deconfound the potential for interference and decay that are typical in long-term memory tests. Nevertheless, it would be informative to assess whether similar effects would be observed under more difficult task conditions, such as by decreasing the amount of time allotted to encode the material.

Finally, we are agnostic as to whether the forgetting of specific and gist memory that occurred from short-term to long-term memory in the present study resulted from temporal decay (e.g., McGeoch, 1932) or interference from intervening events (e.g., Thorndike, 1914). Historically, both time-based decay and interference have been confounded in tests of long-term retention (see Wixted, 2004). Our use of a continuous associative recognition task entails that longer retention intervals featured more time and more intervening events between study and test. Both time-based decay and interference may have played a role in forgetting. However, the goals of our study were not to determine whether forgetting occurs due to the passage of time or from interference. Instead, we sought to determine whether older adults, compared to younger adults, could remember specific details of associations in episodic memory in short-term compared to long-term retention situations, as such comparisons were core to our research question of whether older adults fail to encode or retrieve verbatim representations. We leave it to future research, perhaps employing a modified version of our paradigm, to ascertain whether the loss of specific details from short-term to long-term memory is attributable to decay or interference.

Conclusions

Age-related deficits in the associative aspects of episodic memory are well-established (Naveh-Benjamin, 2000; Old & Naveh-Benjamin, 2008). These deficits are greatest for specific but not gist representations of associations (Greene & Naveh-Benjamin, 2020). We sought to determine whether these deficits would appear on tests of short-term retention, almost immediately after encoding. Our results showed that older adults were able to remember specific details of associations on short-term memory tests, but only when test probes were identical to previously studied pairs and not when test probes were similar. In the latter case, older adults were less likely than younger adults to retrieve specific memory, needed to engage in recollection rejection. Over longer delays, older adults' deficits in specific associative memory were present for test pairs that were identical to studied pairs. These results are largely consistent with a failure among older adults to engage in deeper elaboration during retrieval, even in short-term retention situations.

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