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# How schema knowledge influences memory in older adults: Filling in the gaps, or leading memory astray?

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ABSTRACT

Age-related declines in episodic memory do not affect all types of mnemonic information equally: when to-be-remembered information is in line with one's prior knowledge, or *schema-congruent*, older adults often show no impairments. There are two major accounts of this effect: One proposes that schemas compensate for memory failures in aging, and the other proposes that schemas instead actively impair older adults' otherwise intact memory for incongruent information. However, the evidence thus far is inconclusive, likely due to methodological constraints in teasing apart these complex underlying dynamics. We developed a paradigm that separately examines the contributions of underlying memory and schema knowledge to a final memory decision, allowing these dynamics to be examined directly. In the present study, healthy older and younger adults first searched for target objects in congruent or incongruent locations within scenes. In a subsequent test, participants indicated where in each scene the target had been located previously, and provided confidence-based recognition memory judgments that indexed underlying memory, in terms of recollection and familiarity, for the background scenes. We found that age-related increases in schema effects on target location spatial recall were predicted and statistically mediated by age-related increases in underlying memory failures, specifically within recollection. We also found that, relative to younger adults, older adults had poorer spatial memory precision within recollected scenes but slightly better precision within familiar scenes—and age increases in schema bias were primarily exhibited within recollected scenes. Interestingly, however, there were also slight age-related increases in schema effects that could not be explained by memory deficits alone, outlining a role for active schema influences as well. Together, these findings support the account that age-related schema effects on memory are compensatory in that they are driven primarily by underlying memory failures, and further suggest that age-related deficits in memory precision may also drive schema effects.

## 1. Introduction

Aging consistently leads to episodic memory declines that reduce quality of life, even without pathological cognitive decline (Mol et al., 2007; Wang et al., 2017). Curiously, however, there is a condition in which episodic memory is typically not impaired in older adults: when to-be-remembered information is congruent with their general knowledge of the world—or their *schemas*—older adults perform similarly to young adults (Amer et al., 2018; Castel, 2005; Castel et al., 2013; Delhaye et al., 2019; McGillivray & Castel, 2010; Pitts et al., 2022; Umanath & Marsh, 2014). In contrast, when information is schema-incongruent, older adults exhibit marked deficits (Amer et al., 2018; Castel, 2005; Castel et al., 2013; Delhaye et al., 2019; McGillivray & Castel, 2010; Pitts et al., 2022; Umanath & Marsh, 2014). For example, older adults would likely have little difficulty remembering that their medication is in the medicine cabinet, but could have difficulty remembering its location if it were in the refrigerator—which could have serious consequences for their health and well-being.

The mechanisms driving these age-related schema effects on memory are a subject of debate. One account proposes that schema knowledge is compensatory in aging, in that memory failures cause older adults to use schemas to "fill in the gaps" in their memory (Castel, 2005; Hay & Jacoby, 1999; Umanath & Marsh, 2014). According to this view, older adults' underlying memory is impaired as revealed under incongruent

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conditions, whereas their spared memory performance under congruent conditions is the result of a protective effect of schemas. Another account instead proposes that age-related declines in inhibitory control lead to increases in interference from non-memory influences such as schemas (Amer et al., 2022; Hasher & Zacks, 1988; Lalla et al., 2022). By this account, older adults' "true" underlying memory is largely intact; thus, under congruent conditions, older adults' performance is similar to younger adults' because there is no conflicting schema interference, whereas under incongruent conditions, schema knowledge actively leads older adults astray. In sum, in the context of understanding age differences in schema effects on memory, the former account characterizes schemas as protective and able to compensate for memory loss, whereas the latter account characterizes schemas as a detrimental source of interference that prevents older adults from fully leveraging their memories.

Both theories provide good overall accounts of older adults' superior memory for schema-congruent information, and each can account for different subsets of findings. For example, theories focusing on schemas as compensation could, with minimal modifications, account for findings that older adults' schema effects on memory are primarily observable in the specific type of memory that is impaired by aging (i.e., *recollection*, described in more detail below), rather than all types of memory (Peterson et al., 2017; Prull, 2015; Tinard & Guillaume, 2019; Toth et al., 2011). In contrast, inhibition theories predict age-related schema interference regardless of the type or strength of memory (Lalla et al., 2022). On the other hand, inhibition theories better account for findings that age-related increases in false memory are substantially larger for information that is schema-relevant compared to abstract information (Amer et al., 2022; Hess & Slaughter, 1990; Koutstaal, 2003; Koutstaal et al., 2003). That is, while this finding is well accounted for by theories that age-related deficits in inhibition cause increased interference by schemas, this is not clearly accounted for by schema compensation accounts; specifically, it is not clear why underlying memory loss would lead to more false memory for schema-relevant information in particular. Moreover, a recent study of memory-informed decision-making found that older adults relied less on episodic memory and more on irrelevant schema knowledge than did younger adults, which was taken as support for inhibition theories (Lalla et al., 2022). However, the extent to which participants remembered the studied stimuli, and thus had episodic memory available to rely upon, was not assessed. It is therefore possible that older adults had poorer underlying memory, and schema knowledge was used in an attempt to compensate for it—which would instead support compensation accounts. In sum, based on the evidence to date, it is not clear which theory provides the better account of age-related schema effects on memory.

Perhaps one reason for the conflicting accounts of the source of these age-related schema effects on memory is that extant paradigms have not permitted direct assessment of key assumptions underlying each account. In particular, it has not been possible to tease apart the underlying memory itself from the influence of schemas on memory responses. That is, studies in younger adults indicate that during memory retrieval, schema-relevant memory decisions (e.g., remembering the size or location of studied objects) result from the rational combination of memory representations themselves (i.e., underlying memory) with schema knowledge in a Bayesian fashion, which leads responding to be more schema-congruent (Hemmer & Steyvers, 2009; Huttenlocher et al., 1991; Persaud et al., 2021). The possibility of rational combination of memory representations with schema knowledge at retrieval has not yet, to our knowledge, been examined with respect to memory decline in aging—but separately examining these influences on memory decisions is critical for testing the competing theories of aging. For example, in order to determine whether failures of underlying memory lead older adults to rely more on schemas to fill in the gaps—which is the core proposal of theories that schema effects are compensatory—underlying memory needs to be separated from the final schema-aided memory outcome. In a similar vein, to determine whether older adults' underlying memory is largely intact but their memory decisions are ultimately led astray by schemas—which is the core proposal of inhibition theories of schema effects—underlying memory that is separated from contamination by schema interference needs to be examined. However, paradigms to date have focused on collecting a single memory outcome that represents the final combination of underlying memories with schema influences: whether participants recognize (or recall) the studied schema-congruent or schema-incongruent information (for review, see Umanath & Marsh, 2014). These paradigms have been critical in establishing our foundation of knowledge regarding schema-memory interactions in aging, but to assess evidence for the competing accounts that have arisen from this work, new methods are needed.

A paradigm that teases apart underlying memory from the final schema-influenced memory outcome was recently developed and applied to understanding schema-memory interactions at retrieval in younger adults (Ramey et al., 2022). Specifically, participants searched scenes for target objects in either schema-congruent or schema-incongruent locations during an initial study phase. During a later test phase, participants were shown only the background scenes without the target objects, and were asked to make two types of memory judgments for each scene. First, participants made a spatial recall judgment for where in the scene the target object had been located earlier in the study. Similar to assessments of schema-relevant memory in studies to date, the spatial recall judgment stood to be highly influenced by schema knowledge at retrieval (e.g., whether to recall the object as having been in a congruent or incongruent location), and thus represented a combination of underlying memory and schema effects (Hemmer & Steyvers, 2009; Huttenlocher et al., 1991). After the spatial recall judgment for the target location, participants' recognition memory for the background scene itself was assessed. Importantly, there was no schema information available at retrieval that could be relevant for deciding if they had seen the scene itself, so this scene recognition response served to index memory for the episode that would not be influenced by schema congruency at retrieval (or, at the least, would be less influenced by schema congruency than would the target object location judgment). That is, scene recognition memory indexed underlying memory.[1] By examining how schema congruency differentially influences spatial recall at different levels of underlying memory (i.e., different types and strengths of background scene recognition memory), the extent to which schema effects are related to underlying memory failures can be examined directly.

In our prior work developing this paradigm and replicating the results from it (Ramey et al., 2022; Ramey & Zabelina, 2024), we found that in younger adults, schema effects were strongly related to underlying memory strength. When participants had no underlying memory for the scenes, there were strong schema effects on the final memory

[1] Note that our separate assessment of target memory and scene memory should not be taken to imply that these two forms of memory are independent. Rather, these two forms of memory should be highly dependent: one cannot remember where a target is in a scene without remembering the scene itself to some extent, especially given that the target exemplars were not unique for every scene. The key distinction we drew between these two aspects of memory we assessed was that target memory, in particular, could be systematically influenced by schema knowledge that is specifically available at retrieval. That is, if someone has never seen a given scene before, they could still use schema knowledge to achieve a well-above-chance guess about where a target object is (see performance in new scenes in Figure 2 of Ramey et al., 2022). On the other hand, participants could not use schema knowledge available at retrieval to achieve an above-chance guess about whether a scene was old or new: there was nothing inherently different about the old and new scenes. Schema congruency (of the target at study) had no bearing on whether a scene itself was old or new at test. Therefore, memory for the background scene indexes memory for the episode—which included both target and scene—that is not contaminated (or at least less contaminated) by schema knowledge that could influence decision-making at retrieval.

responses in that spatial accuracy for the target location was substantially better for congruent than incongruent scenes. As underlying memory strength increased, these schema effects on spatial accuracy decreased. Importantly, we found that these effects depended on the type of memory involved: Gist-like *familiarity* led to some decreases in schema effects, whereas only vivid *recollection* led to a complete elimination of schema effects—even when compared to strength-matched familiarity (Ramey et al., 2019; Yonelinas, 2002; Yonelinas et al., 2022). This finding that different memory processes exhibit differential interactions with schema knowledge is particularly relevant for the question of aging effects, given that healthy aging is known to primarily impair recollection with minimal impact on familiarity (Koen & Yonelinas, 2014; Light, 2012). Moreover, age differences in schema effects on memory are primarily exhibited in recollection, rather than familiarity (Peterson et al., 2017; Prull, 2015; Tinard & Guillaume, 2019; Toth et al., 2011). Thus, examining recollection and familiarity within a paradigm that allows those processes to be separated from the final schema-influenced memory outcome may prove particularly fruitful for advancing our understanding of age-related schema effects on memory.[2]

Although the younger adult findings provide clear support for the notion that schema effects on memory retrieval in general are driven by memory failures, it is not yet clear whether this means that *aging* differences are related to memory failures. That is, aging could lead to a separate, inhibition-related effect wherein schema bias is increased diffusely, irrespective of underlying memory strength—which is a direct prediction of inhibition theories (Lalla et al., 2022). Alternatively, aging could increase schema effects by increasing the probability of memory failures. The current study aims to directly test these possibilities.

### 1.1. Current research

In the present study, we leveraged our paradigm outlined above (Ramey et al., 2022) to investigate how schema effects on memory decisions differed between older and younger adults. Specifically, we examined whether age differences in schema effects on memory 1) were predicted and mediated by age differences in underlying memory failures, or instead occurred irrespective of underlying memory, 2) varied according to the precision of the underlying memory representations (even when memory did not fail altogether), and 3) depended on whether memory was underpinned by recollection or familiarity.

In line with prior work, we expected that older adults would have larger schema effects on their memory decisions than would younger adults (Umanath & Marsh, 2014). However, expectations for the dynamics underlying these effects vary by theoretical perspective: If schema effects on memory decisions are protective in aging, then age increases in schema effects should be mediated by age increases in underlying memory failures (Hay & Jacoby, 1999; Umanath & Marsh, 2014). On the other hand, if inhibitory control impairments cause schemas to actively bias older adults away from memory-based responding (Amer et al., 2022), age increases in schema effects on memory decisions should not be mediated by underlying memory failure, but rather should be present across all levels of underlying memory strength and type (Lalla et al., 2022). That is, if age increases in schema bias are not found to depend on age-related deficits in underlying memory, then it would suggest that schemas are actively biasing older adults' otherwise intact memory—which would support inhibition theories.

To test these hypotheses, we took a two-pronged analytic approach by examining both between-subjects memory discriminability effects, and within-subjects dynamics of interactions between schemas and memory at the trial level. The rationale for this approach is that it permits a more nuanced examination of how aging effects on memory occur: It could be that effects occur only at the subject level, only at the trial level, or both. Importantly, differences across these types of analysis help to discriminate between the competing theories. Specifically, underlying memory for the background scenes in our task can be characterized as either 1) subject-level memory discriminability (i.e., objective performance) across many aggregated trials, in terms of each participant's overall ability to successfully discriminate between old and new scenes and the extent to which they rely on recollection or familiarity to do so; or as 2) trial-level reported memory confidence for each old scene, which can be recollected or vary along a continuum of familiarity strength. To use recollection as an example, the subject-level measure indexes the extent to which successful recollection occurs; this is how aging reductions in recollection (vs familiarity) have been demonstrated in prior work (Koen & Yonelinas, 2014). The trial-level measure reveals what happens when participants *do* recollect a scene; that is, the quality and precision of their recollected representations, and how age might change how recollection interacts with schemas when recollection does occur.

Examining underlying memory using both of these methods allows us to better assess evidence for and against each account of schema-memory interactions in aging. Inhibition theories explicitly predict that age-related increases in schema effects will be constant across different levels of memory strength (Lalla et al., 2022). If this is the case, we should find that age increases in schema bias are independent from age differences in subject-level memory discriminability. Moreover, at the trial level, older adults should exhibit more schema bias than younger adults at every level of memory strength examined (i.e., within recollected scenes, and at all levels of familiarity strength). Thus, the specific pattern of results that would support inhibition theories would consist of 1) age increases in schema bias of target object memory that are not mediated by age decreases in recognition performance (memory discriminability) for the background scenes, 2) age increases in schema bias that appear in all types of scene memory examined, and 3) no age-related interactions between schema congruency and scene recognition in predicting target object memory, such that the age increase in schema bias should be of roughly equal magnitude across different scene memory responses.

The competing account that schemas compensate for age-related memory decline predicts the opposite pattern of results: Age-related increases in schema bias should only occur in the context of age-related decreases in underlying memory. Therefore, the strongest direct prediction of these theories for the present study is that age increases in schema bias should be mediated by age decreases in memory discriminability at the subject level. Moreover, at the trial level, we propose the novel but related prediction that the type(s) of memory for which older adults have poorer precision relative to younger adults should exhibit the largest age increases in schema bias, based on emerging findings that aging primarily leads to losses in memory precision rather than likelihood of remembering (Korkki et al., 2020; Nilakantan et al., 2018). That is, we propose that schema bias should increase not only under conditions of increased memory failures (i.e., age-related increases in the number of stimuli that are forgotten), but also under conditions of reduced memory quality even when some memory is present (i.e., age-related reductions in the precision of remembered representations). Additionally, given that memory decline

[2] With respect to separating memory from schemas, our focus was specifically on retrieval. Effects of schema congruency at encoding were expected to influence resulting memory, with a higher likelihood of recollection for incongruent scenes (see Supplementary Material; Lampinen et al., 2001). Moreover, it is likely that at retrieval, participants sometimes recollected schema-related information that they had encoded previously. Our paradigm and analytic method were specifically designed to control for these effects: we were only concerned with how schemas *at retrieval* affected memory decisions at a given level of underlying memory that had already resulted from encoding. How those underlying memories were formed was not relevant to our question; the congruency-based analyses were conditionalized on the type and strength of memory that had already been formed. Moreover, follow-up analyses were conducted to ensure that effects were robust when controlling for encoding effects.

in aging is largely limited to recollection (Koen & Yonelinas, 2014), and age-related schema effects on memory are primarily related to recollection (Peterson et al., 2017; Prull, 2015; Tinard & Guillaume, 2019; Toth et al., 2011), we expected both the subject-level and trial-level age differences to be most evident in recollection. If these predictions are borne out, then the pattern of results we should observe is 1) age increases in schema bias of target object memory that are mediated by age decreases in recognition performance, particularly in terms of recollection, for the background scenes, 2) age differences in schema bias when target object memory is examined within recollected, but not familiar, scenes, and 3) more age-induced schema bias in the type(s) of scene memory for which age-induced precision deficits are larger. Regardless of which pattern of results is observed, however, the present study will be informative for understanding the effects of aging on interactions between schemas and memory at retrieval.

## 2. Method

### 2.1. Participants

A total of 70 participants completed the study and successfully passed all pre-experimental attention checks to ensure they understood the instructions. Of these, 35 were older adult participants (age range = 62–87 years; $M = 76$ years), and 35 were younger adult participants (age range = 18–23 years; $M = 20.1$ years). We determined this sample size via a power analysis: A sample size of 35 participants provides 95% power to detect the most relevant previously observed effect, which we obtained in a prior study ($d_z = 0.63$ for suppression of schema congruency effects by recollection, which was the interaction of congruency with recollection versus strength-matched familiarity; Ramey et al., 2022). Older adult participants were recruited via email from an established local participant pool of cognitively healthy older adults (Dave et al., 2021). Younger adult participants were undergraduate students recruited through the psychology participant pool.

Participants were removed from analysis for technical issues or for failing to properly complete the task; specifically, due to providing a response on <75% of trials, being at or below chance recognition performance (AUC), or having atypical mouse coordinates that did not conform to the typical browser output. Two participants' data needed to be removed as a result of providing an insufficient number of responses; the average response rate in the remaining participants was 95.3%. Thus, the final sample consisted of 33 older adults and 35 younger adults.

### 2.2. Apparatus

The study was conducted online using JavaScript via jsPsych, which allows for accurate, high-speed presentation timing and response recording (de Leeuw, 2015). Although all participants were members of local participant pools, the study was conducted online due to COVID-19 precautions. Participants were provided with technical assistance from a researcher over the phone as needed. Participants were instructed to use a computer with a browser size of at least 800 × 600px; any participants who tried to use a phone or tablet were not permitted to complete the experiment. The experiment would not begin if a participant's browser size was <800 × 600px but allowed them to continue once they expanded it sufficiently. Participants were able to see their cursor throughout the experiment.

### 2.3. Stimuli

Stimuli were 80 photographs of real-world scenes. All scenes were presented in color at a resolution of 800×600 pixels. Of these 80 scenes, 60 were presented at study and test (i.e., old scenes), and 20 were presented only at test (i.e., new scenes). We included more old scenes than new scenes to ensure that an adequate number of old scenes was recognized at each level of confidence for analysis. Stimulus presentation was counterbalanced, such that the scenes appeared in different conditions (i.e., presented at both study and test, or used as a new lure during test) for different participants to mitigate stimulus effects.

Five scene categories were used, and a single type of target object was used for each category. The categories and targets consisted of kitchens (target: frying pan), dining rooms (target: wine glass), bedrooms (target: alarm clock), living rooms (target: coffee mug), and bathrooms (target: toothbrush cup). Eight different object exemplars were used per category, such that the visual features of the target object varied across different scenes within a category. In each scene, only one exemplar of the target object was present, and this was kept consistent across presentations. For example, in each living room scene, there was only one coffee mug present. Importantly, for a given scene viewed by a given participant, the target was always visually identical and in the same location across repeated study phase viewings (note that targets were never present in the test phase).

Two versions of each scene were created using Adobe Photoshop (Fig. 1A-D): one with the target object in a schema-congruent location, and one with the target in a schema-incongruent location. The congruent location was consistent across all scenes in a category, such that targets were placed relative to larger objects with which the target objects co-occur with high probability in daily life (Boettcher et al., 2018; for review of scene grammar see Võ et al., 2019). Specifically, the congruent locations were as follows: in bathroom scenes, the toothbrush cups were located next to sinks; in dining room scenes, the wine glasses were located on tables (within arm's reach of a chair); in kitchen scenes, the pans were on stove burners; in bedroom scenes, the alarm clocks were on bedside night stands; and in living room scenes, the coffee mugs were on coffee tables. In incongruent scenes, on the other hand, the objects were arbitrarily placed in unexpected but physically plausible locations (i.e., on floors, shelves, chairs, etc.). The types of surfaces on which incongruent targets were placed varied between scenes, both within and between categories. The surface areas of the locations, and the distributions of target locations, were similar between conditions (see Supplementary Material). To validate the congruency manipulation, we also had a separate group of participants ($n = 25$) rate each scene for the congruency of its target object on a continuous scale. Specifically, participants were asked to rate how normal or unusual a target's location was on a 1–6 scale. These scores were averaged together to produce a congruency score for each scene. As expected, congruent scenes were rated as significantly more congruent than were incongruent scenes, $p < .0001$. These results verify that the congruency manipulation had the intended effect.

Scene congruency was manipulated within-subjects such that each participant was presented with half incongruent scenes and half congruent scenes. The congruent and incongruent versions of the scenes were also counterbalanced such that half of the participants saw the congruent version of a given scene, whereas the other half saw the incongruent version of that same scene. Importantly, a given scene was always congruent or incongruent within a given counterbalance, such that the target was always in the same place in a scene across study repetitions for a given participant.

### 2.4. Procedure

The experiment lasted approximately 45 min and consisted of a study phase followed by a test phase (Fig. 1E-F). There was a 2-min break between the study and test phases. Before each phase, participants were given instructions as well as three practice trials to familiarize them with the procedure. Participants were given a break midway through each phase. All procedures were approved by the university Institutional Review Board.

#### 2.4.1. Study phase

Participants were told that they would be searching for and clicking

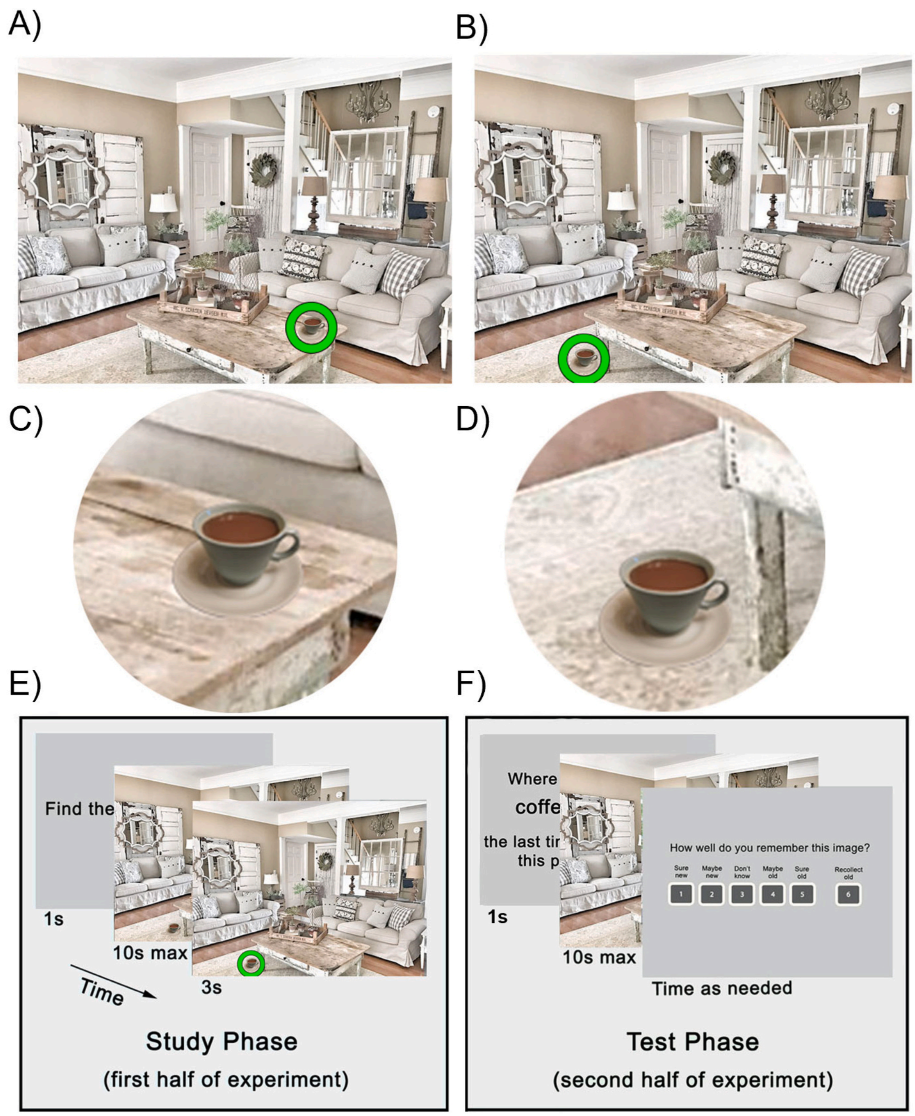


**Fig. 1.** Sample stimuli and procedure. A) The congruent version of a sample scene, with the target object (coffee cup) on the coffee table. The ring appeared around the target after participants clicked on the scene in the study phase. B) The incongruent version of the scene. C) Closeup of the target object in the congruent scene (for visualization only; this was not part of the experiment). D) Closeup of the target object in the incongruent scene. E) The trial sequence in the study phase, which consisted of 60 scenes presented two times each (120 trials). In each trial, a target probe appeared (e.g., "Find the coffee cup"), followed by the scene with target object. Participants were required to click on the target object within 10s. After clicking or after 10s, whichever occurred first, a green ring appeared around the target for 3 s. F) The trial sequence in the test phase, which consisted of 80 scenes, 20 of which were new (80 trials). A target probe appeared, followed by the scene without the target object, and participants were given 10s to click on the scene location that they thought had contained the target when the scene was presented in the study phase. After 10s or clicking, whichever occurred first, participants gave a confidence-based recognition memory response for the scene.

on target objects and were asked to try to remember the scene and object locations for a later memory test. During the study phase, participants were presented with 60 unique scenes that were each shown twice, for a total of 120 trials. The repetitions were randomly intermixed throughout the study phase, with the requirement that the same scene did not appear twice in a row. In each trial, participants were first given a 1 s probe alerting them to the target object they would need to search for. For example, for dining room scenes, the probe was "Find the wine glass." After the probe, the scene appeared, and participants had 10s to click on the target object in the scene. After clicking on the scene, or after 10s had elapsed, a green ring appeared around the target object and remained for 3 s to allow participants to encode the scene and target object location (Fig. 1A-B).

### 2.4.2. Test phase

In the test phase, participants were asked to recall where the target object had been located in each scene when they had seen it during the study phase, and to provide a confidence-based recognition memory judgment for each scene. Participants were told that even if they thought that a scene was new (i.e., not presented in the study phase), they should make their best guess for where the target object might have been if the scene had in fact been shown in the study phase—that is, if their recognition memory had failed and it actually was an old scene. The test phase included 80 scenes, 60 of which were presented in the study phase and 20 of which were new lures. Each scene was presented once, for a total of 80 test trials. Each trial began with a 1 s target probe (e.g., "where was the wine glass the last time you saw this picture?"), followed by the presentation of a scene without its target object, and participants were given 10s to click on the location in the scene where they remembered having seen the target object in the study phase. After clicking, or after 10s elapsed, a recognition memory response scale appeared and participants were given time as needed to respond.

Memory strength was measured by asking participants to rate memory confidence for each scene on a 6-point scale during the recognition judgment (Yonelinas, 2002). Participants were told that if they could consciously recollect some qualitative aspect of the initial learning event, such as what they thought about when the scene was encountered earlier, they should respond "Recollect old (6);" otherwise, they rated their memory confidence by responding "I'm sure it's old (5)," "Maybe it's old (4)," "I don't know (3)," "Maybe it's new (2)," or "I'm sure it's new (1)." Importantly, participants were instructed that a "sure old" response was equal in confidence to a "recollect old" response, such that the only difference between them was that at least one specific detail of the learning event was remembered in recollected scenes. Participants were instructed and tested on how to use this scale prior to beginning the test phase.

### 2.5. Data reduction and analysis

The primary outcome of interest was *target distance:* the Euclidean distance between the location clicked by participants during the spatial recall portion of the test phase and the actual location of the target object when the scene was presented in the study phase. This was measured in pixels between the mouse position during the click, recorded in terms of coordinates on the 800x600px scene, and the center of the target object. The target distance measure was skewed, so it was log-transformed.

Two analytic strategies were used: one at the subject level, using memory discriminability estimates, and the other at the trial level, using memory responses. We describe each in more detail in the following sections.

#### 2.5.1. Memory discriminability analysis (subject-level)

Memory discriminability estimates were obtained using the remember/know estimation procedure (Yonelinas, 2002). (Note that because of time constraints on the procedure, there were insufficient trials per condition for dual-process signal detection model estimation.) Recollection was estimated as the proportion of recollect responses to old scenes minus the proportion of recollect responses to new scenes. To estimate familiarity, responses of 4 and 5 ("maybe old" and "sure old") were first collapsed into a single "familiarity" bin, rendering the responses analogous to a standard remember/know paradigm. Familiarity for old scenes was estimated as the probability of a familiarity response to an old scene divided by one minus the probability that an old scene received a recollect response. Familiarity for new scenes was estimated as the probability of a familiarity response to a new scene divided by one minus the probability that a new scene received a recollect response. Familiarity estimates were calculated by subtracting familiarity for new scenes from familiarity for old scenes.

For these subject-level analyses, *schema bias* scores were calculated for each participant. To do this, participants' average target distance on congruent scenes was subtracted from their average target distance on incongruent scenes. Higher numbers correspond to more schema bias, as they reflect a larger difference in spatial recall performance between congruent and incongruent scenes.

Statistical analyses for the relationship between schema bias and memory discriminability were conducted using Pearson correlation, and for examining interactions, linear regression. Statistical mediation was tested using Sobel mediation tests, which allow for assessment of the extent to which a potential mediating variable mediates the relationship between an independent variable and a dependent variable, using the *bda* package in R. (Note that statistical mediation does not assess causality in this case, but rather allows one to examine interrelationships in how different independent variables predict an outcome.)

#### 2.5.2. Memory response analysis (trial-level)

For trial-level analyses, the effects of underlying memory on final memory decisions were examined by comparing the target distance values between scenes given different recognition responses, and examining age differences in these effects. Specifically, target distance was compared across non-recollected responses (1–5) to assess familiarity strength, and within recollect responses (6) to examine recollection. To examine differences between recollection and strength-matched familiarity, effects were compared between recollected and "I'm sure it's old" responses (6 versus 5; Ramey et al., 2020).

Target distance in new scenes was assessed for comparison with old scenes. Given that new scenes were never presented with a target object, they were not inherently congruent nor incongruent and did not have a true target location. Whether a new scene was classified as congruent or incongruent—and therefore, which target location was used for computing target distance—was determined by the condition in which participants in the opposite counterbalance saw the scene during study (i.e., if participants in counterbalance 1 saw the target as congruent in a scene during the study phase, that scene was considered to be congruent in counterbalance 2 in which participants saw it as a new scene). Thus, to measure target distance in new scenes, we calculated the distance between the clicked location in the test phase and the target location when it was shown in the study phase for participants in the opposite counterbalance. Participants' clicks on new scenes represented their best guess for where the target object might have been located based on their schema knowledge and their knowledge of the experiment.

All trial-level analyses were conducted using linear mixed effects models with random intercepts of subject and image, as well as random slopes allowing the predictor of interest to vary by subject and image (see Supplementary Material for model equations, Eq. S1-S4). These multilevel models allowed us to harness trial-by-trial (i.e., within-subjects) data while accounting for dependencies in the data (e.g., trials nested within subjects), and controlling for individual differences and stimulus effects. The models were estimated using the *lmerTest* package in R (Kuznetsova et al., 2017) using restricted error maximum likelihood. The degrees of freedom were calculated using the Satterthwaite approximation and were rounded to the nearest integer in the manuscript. Effect sizes were calculated as a standardized regression coefficient (β) for continuous variables, and *d*, calculated as $2t/\sqrt{df}$ (Rosenthal & Rosnow, 1991), for categorical variables. Marginal and conditional $R^2$ values are also provided in the Supplementary Material (Table S1). For the follow-up analysis of whether participants clicked on a congruent region, outcomes were binary, so mixed effects logistic regression models were used and the estimate (*B*) is reported.

To quantify the evidence in favor of the null for nonsignificant results obtained using frequentist statistics, we computed Bayes factors (using the *BayesFactor* package in R with 5000 iterations) and assessed $BF_{10}$—that is, the ratio of the Bayes factor in favor of the alternative hypothesis to the Bayes factor in favor of the null hypothesis. By convention, a $BF_{10} < 0.33$ indicates substantial evidence for the null hypothesis, and a $BF_{10} < 0.10$ indicates strong evidence for the null (Jeffreys, 1961).

## 3. Results

### 3.1. Age differences in scene memory

First, we examined age differences in background scene recognition (i.e., underlying memory) independent of target judgments. In line with prior work (Koen & Yonelinas, 2014), across all scenes, older adults had lower recollection estimates ($M_{older} = 0.21$, $M_{younger} = 0.33$), $t(66) = -3.06$, $p = .003$, $d = -0.75$, but no significant difference in familiarity estimates ($M_{older} = 0.36$, $M_{younger} = 0.42$), $t(66) = -1.54$, $p = .13$, $d = -0.38$ (see Fig. S1). Therefore, our older adult sample exhibited the standard pattern of age effects on episodic memory processes wherein recollection is impaired but familiarity is largely spared (Koen & Yonelinas, 2014).

### 3.2. Age differences in schema-memory interactions

#### 3.2.1. Subject-level effects

We first tested the possibility that age-related schema effects on memory are driven by compensation for memory failures. To do this, we examined whether age-related increases in schema effects were predicted—and mediated—by age-related increases in underlying memory failures. Specifically, we examined how participants' difference scores in spatial recall accuracy for target location between schema congruent and incongruent scenes (i.e., their *schema bias*) varied according to their recognition accuracy for the background scenes themselves. Older adults exhibited higher schema bias than younger adults overall, $t(66) = -3.55$, $p = .0007$, $d = -0.87$, which confirms that there were age-related increases in schema effects on memory decisions. Across all participants, lower recollection estimates predicted higher schema bias, $r = -0.45$, $p = .0001$ (Fig. 2). This was particularly driven by older adults, such that the correlation was significant within older adults, $r = -0.45$, $p = .008$, but only trending in younger adults, $r = -0.28$, $p = .10$; the interaction by age was not significant, $t(64) = 1.37$, $p = .18$. More critically, age increases in schema bias were statistically mediated by age decreases in recollection, $z = -2.18$, $p = .029$. That is, rather than age increases in schema bias and age decreases in recollection comprising two independent effects of aging on cognition, the statistical mediation analysis suggests that age increases in schema bias were fundamentally related to age decreases in recollection. In contrast, familiarity estimates did not predict schema bias across age groups, $r = -0.08$, $p = .53$, in older adults alone, $r = -0.04$, $p = .83$, or in younger adults alone, $r = 0.02$, $p = .90$. Moreover, age differences in schema bias were not significantly mediated by age differences in familiarity, $z = 0.02$, $p = .99$.

Together, these findings indicate that failures in underlying memory predict increased schema effects in aging. However, they also make clear that the effects are more nuanced than simply reflecting weak memory, as they were specifically driven by reductions in recollection. We next decompose these effects at the trial level, as well as more directly test predictions of inhibition theories of age-related schema effects on memory.

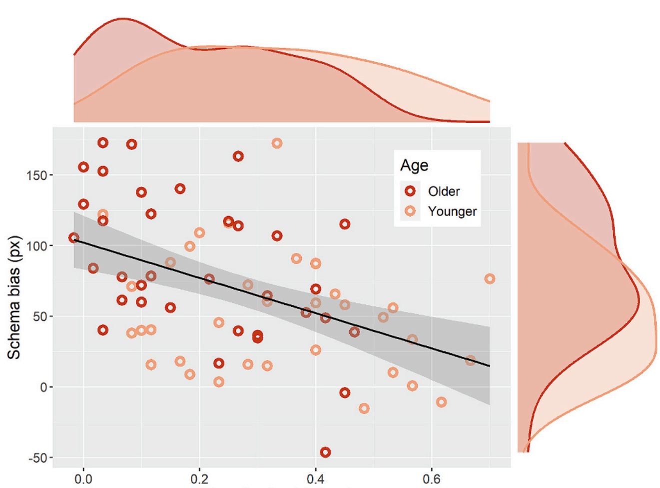


**Fig. 2.** Lower recollection estimates for the background scenes predict higher schema bias in target recall. Shaded region surrounding regression line is standard error. Raw (target distance not log-transformed) schema bias values are presented. Density plots for schema bias and recollection estimates are presented on their respective axes, colored by age group. The relationship between recollection and schema bias, combined with the mediation analysis, indicates that age-related decreases in recollection statistically mediate age-related increases in schema bias. These effects were not observed with respect to familiarity.

#### 3.2.2. Trial-level effects

*3.2.2.1. Separate contributions of schemas and scene memory to spatial recall.* First, we examined age differences in how test phase spatial recall accuracy for target location varied between scenes that were congruent versus incongruent at study. As expected, spatial accuracy was generally better for congruent than incongruent scenes (i.e., lower target distance in congruent than incongruent scenes) for both older adults, $t(75) = 5.68$, $p < .0001$, $d = 1.31$, and younger adults, $t(78) = 3.64$, $p = .0005$, $d = 0.83$. This indicates that both younger and older adults used schema knowledge when making target location judgments. Converging with the subject-level schema bias effects outlined above, this effect was larger for older than younger adults, $t(65) = -3.46$, $p = .001$, $d = -0.86$ (Eq. S1), indicating that schema knowledge exerted more of an influence on older adults' spatial accuracy (Fig. 3a).

We then examined how spatial accuracy varied with scene memory. In terms of scene memory strength, spatial accuracy in old scenes improved with stronger scene memory across all recognition responses in both older adults, $\beta = -0.23$, $t(40) = -7.48$, $p < .0001$, and younger adults, $\beta = -0.40$, $t(64) = -9.95$, $p < .0001$. Critically, this effect was stronger in younger than older adults, $t(54) = -4.68$, $p < .0001$, $d = -1.28$ (Eq. S2), such that changes in scene memory strength had larger effects on spatial accuracy in younger than older adults (Fig. 3b). Converging with this, the spatial accuracy benefit—collapsed across all responses—for old scenes compared to new scenes was larger in younger than older adults, $t(68) = -2.67$, $p = .009$, $d = -0.65$ (for interaction).

Taken together, these findings reveal two parallel effects: one, that older adults' spatial recall was more influenced by schemas than younger adults', and two, that younger adults' spatial recall was more influenced by scene memory than older adults'. (Note that these effects were independent in the sense that one effect did not necessitate the other.) This converges with the subject-level findings and extends them to show that older adults' underlying episodic memory, even when it is available (e.g., when an old scene is remembered), is less beneficial or perhaps less relied upon for spatial accuracy than is younger adults'.

Decomposing the age difference in the effects of scene memory on spatial accuracy revealed that recollection was the primary driver (Fig. 3b): When recollection responses (6: "recollect old") were removed, and the effect of memory strength on spatial accuracy was examined across non-recollected responses (1: "sure new" through 5: "sure old"), there were no age differences, $t(148) = -1.44$, $p = .15$, $d = -0.24$ (Eq. S3a), and there was substantial evidence for the null, $BF_{10} = 0.018$. However, when spatial accuracy was examined only within recollected scenes, spatial accuracy was significantly lower in older than younger adults, $t(54) = -4.78$, $p < .0001$, $d = -1.30$ (Eq. S4a)—that is, older adults' memory precision in recollected scenes was lower than younger adults'. This was the case not only in incongruent scenes, $t(52) = -5.02$, $p < .0001$, $d = -1.40$, but also in congruent scenes, $t(41) = -3.01$, $p = .004$, $d = -0.94$ (Fig. 4). In contrast, there were no age differences in spatial accuracy within familiar scenes (collapsed across responses 2–5),[3] $t(64) = 0.5$, $p = .62$, $d = 0.13$ (Eq. S3b), in either incongruent scenes, $t(64) = -1.14$, $p = .26$, $d = -0.28$, or congruent scenes, $t(68) = 1.21$, $p = .23$, $d = 0.29$ (Fig. 4). Bayes factor analysis provided substantial evidence for the null hypothesis for a lack of age-related precision deficits in familiarity, $BF_{10} = 0.087$. This was also significant when compared to recollection directly: The age difference in precision was significantly larger for recollected scenes than strength-

[3] This held regardless of the criteria that were used to define "familiar scenes": all non-recollected responses, responses of 2–5 that include both weak and strong familiarity (our operationalization), responses of 4–5 that include stronger familiarity, or solely responses of 5 that correspond to familiarity that is matched in strength to recollection. That is, the results were still null, and the Bayesian evidence in favor of the null was still substantial, irrespective of which non-recollected responses were included.

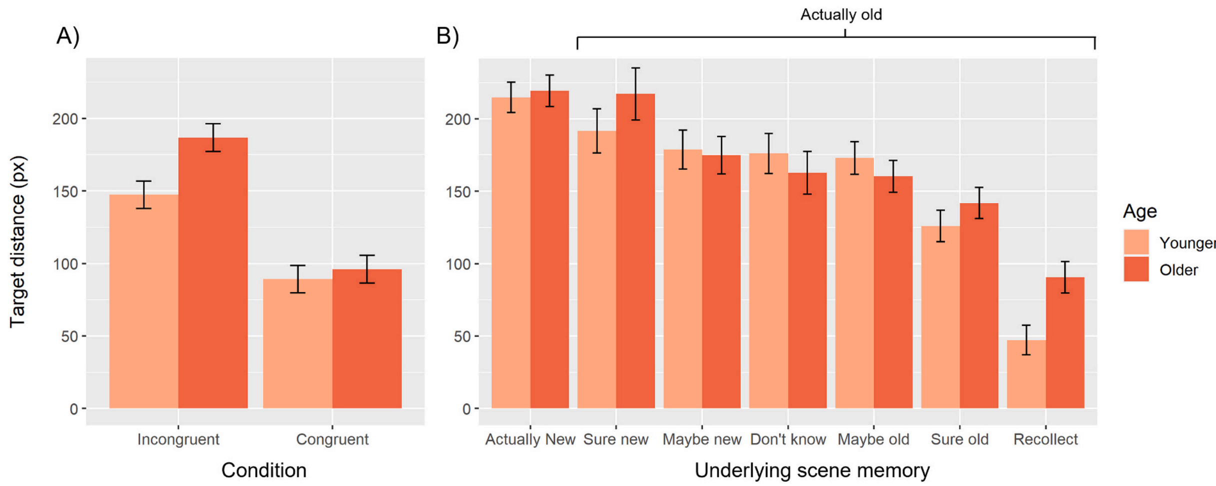


**Fig. 3.** Age differences in the separate influences of schemas and underlying memory on spatial memory decisions. A) Age differences in schema congruency effects on spatial recall accuracy in old scenes. Higher target distance values reflect lower spatial accuracy. B) Target distance across memory responses (collapsed across congruency conditions), illustrating that age differences in the effect of underlying memory on target distance were driven by recollection in particular. For both plots, the estimated marginal means derived from a linear mixed effects model are plotted, and the error bars represent the standard error of these estimated means from the model; raw (not log-transformed) target distance values are presented.

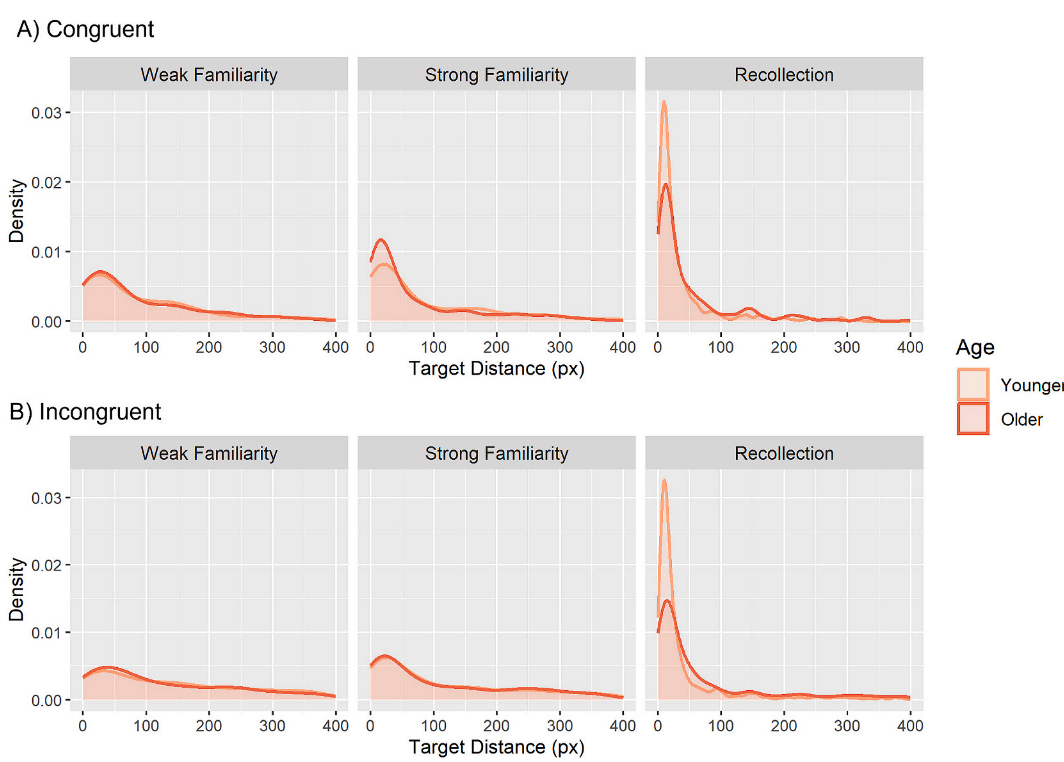


**Fig. 4.** Density plots of the distribution of spatial recall responses by condition, scene memory type, and age. Weak familiarity included "maybe it's new" and "I don't know" responses, strong familiarity included "maybe old" and "I'm sure it's old" responses, and recollection included "recollect old" responses. Raw target distance scores are presented, but note that, as specified in the method, target distance was log-transformed for analysis given its skew. A) Congruent scenes. B) Incongruent scenes.

matched familiar scenes, $t(58) = -2.55$, $p = .014$, $d = -0.67$ (Eq. S4b), as well as all familiar scenes when they were collapsed, $t(60) = -4.92$, $p < .0001$, $d = -1.27$. Together, this indicates that, unlike with recollection, the precision of familiarity-based memory was not impaired by aging. This suggests that reductions in the contribution of underlying memory to spatial recall in aging were driven by less precise recollection in older adults.

*3.2.2.2. Interactions between schemas and scene memory.* We next examined age differences in the interactions between schemas and scene memory in predicting spatial accuracy within old scenes. As in our prior work, there was no significant effect of schema congruency within recollected scenes in younger adults, $t(59) = 1.40$, $p = .17$, $d = 0.36$, such that schema congruency no longer influenced spatial recall when recollection-based memory was available. In older adults, however, schema congruency continued to significantly influence spatial accuracy when scenes were recollected, $t(44) = 2.89$, $p = .006$, $d = 0.87$. This difference between older and younger adults was significant, $t(52) =$

−2.33, $p$ = .023, $d$ = −0.64 (Eq. S4c), such that the effect of schema congruency in recollected scenes was larger in older adults (Fig. 5a). This indicates that even when older adults had confident, recollection-based memory for a scene, schema knowledge continued to influence their spatial recall decision—whereas recollection suppressed schema effects entirely in younger adults. This age difference appeared to be related to reduced recollection precision in older adults: At the subject level, age increases in overall schema bias (i.e., aggregated across all trials) were statistically mediated by age decreases in precision (i.e., target distance) within recollected scenes, $z$ = −2.39, $p$ = .017.

To assess the effects of familiarity strength, we compared spatial recall accuracy across the linear gradient of responses from "sure new" (no familiarity) to "sure old" (strong familiarity) in old scenes. The influence of schema congruency on spatial accuracy decreased as familiarity strength increased in both younger adults, β = −0.15, $p$ = .007, $t$(88) = −2.79, and older adults, β = −0.10, $p$ = .035, $t$(149) = −2.12. There was no significant difference between younger and older adults in the interaction between familiarity strength and congruency in predicting spatial accuracy, $t$(77) = −0.52, $p$ = .60, d = −0.12 (Eq. S3c), and Bayes factor analysis provided substantial evidence for the null effect, $BF_{10}$ = 0.013. This indicates that age did not influence the extent to which increases in familiarity strength predicted decreases in schema congruency effects on spatial accuracy. Moreover, age differences in familiarity precision did not statistically mediate age increases in schema bias, $z$ = −0.64, $p$ = .52.

In addition to examining changes in schema effects across different levels of familiarity strength, we also examined age differences in schema effects within familiar scenes overall, collapsed across strength. Schema congruency effects on spatial accuracy within familiar scenes were marginally higher in older than younger adults, $t$(59) = −1.9, $p$ = .056, $d$ = −0.50 (Eq. S3d). The effect was significant when all non-recollected scenes were examined (i.e., including "sure new" scenes), $t$(60) = −2.08, $p$ = .04, $d$ = −0.54. That is, despite strong evidence for a lack of age differences in familiarity itself, older adults still exhibited marginally more schema bias overall in familiar scenes (in addition to recollected scenes). This suggests that although memory deficits—as indexed either by poorer discriminability or poorer precision—successfully account for most of the presently identified age differences in schema effects, memory deficits may not fully account for all of the observed age-related increases in schema effects.

### 3.3. Follow-up analyses

We next assessed the robustness of the effects we obtained by conducting converging analyses and controlling for potential encoding-related influences. Specifically, we examined the tendency to click on congruent regions, and the extent to which search times and schema bias at encoding may have influenced effects.

#### 3.3.1. Clicking on congruent regions

Thus far, we have used differences in spatial accuracy between congruent and incongruent scenes to index schema bias. To examine schema-based target recall decisions more directly, we determined whether each click was made on a congruent region; for example, for a coffee cup, clicks anywhere on the coffee table would be considered a congruent click. Importantly, remembering the target location would inevitably produce more congruent clicks in congruent scenes, and fewer in incongruent scenes, even if those choices were not driven by congruency per se. To control for this statistical inevitability, we covaried target distance in analyses to examine effects that were related to clicking on congruent regions irrespective of specific memory for the target location.

Within recollection, older adults were not significantly more likely to click on congruent regions when collapsed across congruency condition, $B$ = 0.26, $p$ = .14; this is likely driven by younger adults' numerically higher likelihood of clicking congruent regions in congruent scenes

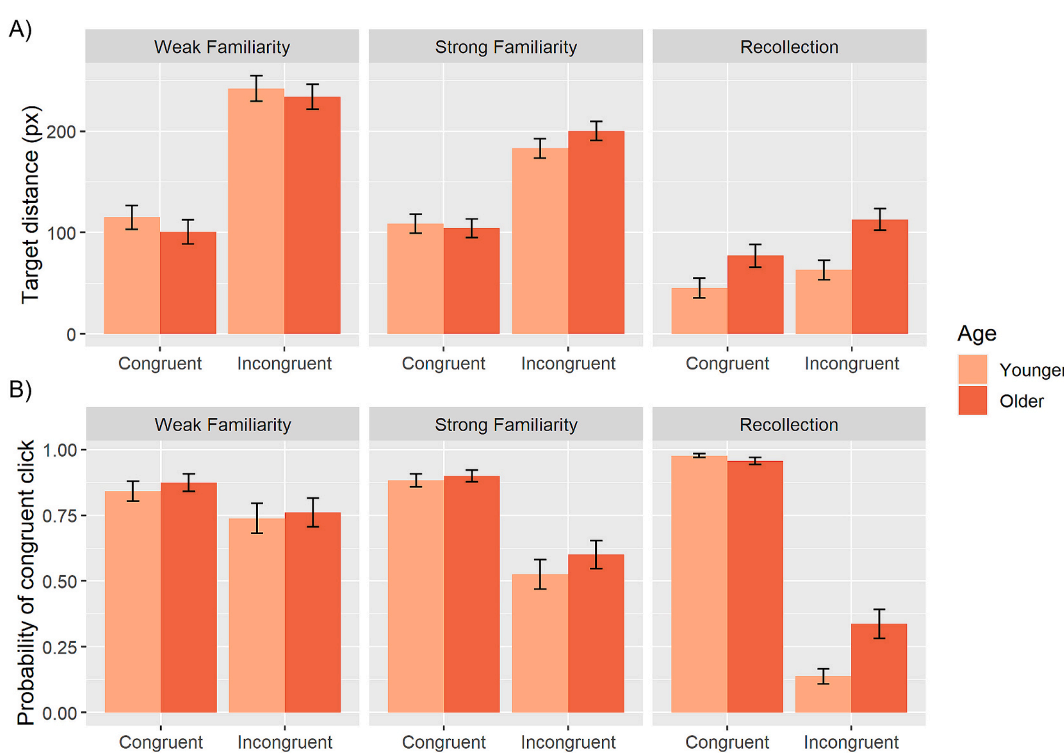


**Fig. 5.** Age differences in interactions between schemas and underlying scene memory. A) Age differences in target distance by congruency, separated by response: weak familiarity ("maybe it's new" and "I don't know"), strong familiarity ("maybe old" and "I'm sure it's old"), and recollection ("recollect old"). B) Age differences in the probability of clicking on a congruent region, controlling for target distance. This indexes differences in the likelihood of clicking congruent regions that are not simply driven by spatial memory.

(Fig. 5b). Supporting this, there was a significant interaction with congruency such that older adults were more likely to click on congruent regions in incongruent scenes than were younger adults, $B = 2.16$, $p = .018$. There were no significant age-related main effects or interactions within familiar scenes, $ps > 0.25$. Overall, these results converge with the main analyses to indicate that age-related increases in schema bias primarily occur within recollection-based memory.

#### 3.3.2. Effects related to encoding

Given that schemas likely interacted with memory at both encoding and retrieval (Dijksterhuis & van Knippenberg, 1995; Greve et al., 2019), we examined the extent to which schema-memory interactions at encoding could have influenced our effects. In particular, it is possible that age differences in the observed schema effects on retrieval—particularly for the subject-level analyses—could result in part from age differences in schema effects on encoding. To examine this possibility, we first assessed whether there were age differences in how schema congruency influenced recollection and familiarity for the scenes. There were no age differences in how schema congruency at encoding influenced subsequent recollection or familiarity estimates; that is, recollection and familiarity estimates varied by congruency condition in similar ways across younger and older adults, $ps > 0.25$ (see Supplementary Material).

We also assessed whether age-related increases in schema bias at encoding could produce poorer recollection, and therefore produce the relationship we observed between recollection and schema bias at retrieval. To examine this, we created a schema bias score for search reaction times during encoding using the same procedure that we used to create the schema bias score for target distance at retrieval (i.e., difference score between congruent and incongruent scenes). We found that schema bias at encoding was not related to recollection estimates, $r = 0.09$, $p = .45$. Moreover, the relationship between recollection estimates and target distance (i.e., retrieval) schema bias was still robust when encoding schema bias was controlled for both overall, $\beta = -0.46$, $p = .0001$, $t(65) = -4.12$, as well as specifically within older adults, $\beta = -0.41$, $p = .018$, $t(30) = -2.50$. This suggests that the effects were not driven by encoding influences.

A similar potential issue is that congruency-related or age-related differences in encoding time may have influenced our findings. To examine this issue, we reran all of our trial-level analyses controlling for encoding time—that is, the sum of study phase search reaction times for a given scene for a given participant. The slight age increase in overall schema bias within non-recollected scenes (i.e., the age-related schema bias that could not be accounted for by underlying memory differences) became only marginally significant, $p = .06$. All other significant effects held, $ps \leq 0.01$, and in fact nearly all of them were considerably strengthened when the covariate was included. All null effects also remained null, $ps > 0.05$, except in one case. Specifically, controlling for encoding time revealed a double dissociation between recollection and familiarity: Whereas older adults had poorer spatial accuracy than younger adults across congruency conditions in recollected scenes, $p < .0001$—as reported in the main analyses—older adults had slightly *better* spatial accuracy than younger adults in non-recollected scenes overall when encoding time was controlled for, $t(83) = 2.22$, $p = .029$, $d = 0.49$, and in only familiar scenes as well, $t(80) = 2.08$, $p = .041$, $d = 0.47$. Probing this effect further suggests that it was not driven by differences in guessing ability (see Supplementary Material). This suggests that older adults may be slightly more effective than younger adults at leveraging familiarity-based memory to improve spatial accuracy; at the least, this demonstrates a robust lack of age-related impairments in familiarity precision.

Overall, these follow-up analyses converge to demonstrate that the observed age-related increases in schema bias within recollection are robust across methods of assessing schema bias, and that the age differences in retrieval schema-memory interactions were likely not driven by age differences in encoding schema-memory interactions.

## 4. Discussion

In the present study, we examined the dynamics underlying age-related schema effects on memory retrieval. Specifically, we assessed evidence for and against the two prevailing accounts of how schemas influence older adults' memory, and further tested whether the precision and type of underlying memory play a role in age-related schema effects. To this end, participants first searched scenes for a target object that was in either a schema-congruent or a schema-incongruent location. In a subsequent spatial recall phase, participants were shown studied and new scenes without the targets present, and indicated where in each scene they thought the target object had been located in the earlier search task. Immediately after each target recall judgment, participants gave a confidence-based recognition memory judgment for the scene—also without the target present—that allowed us to separate underlying memory for the scene (in terms of recollection and familiarity strength) from schema influences present at retrieval. We used two converging analytic approaches including estimates of memory discriminability based on recollection and familiarity at the subject level, and multilevel modeling of the trial-level dynamics of how schema influences on spatial recall varied according to underlying scene memory strength and type. We found support for theories that schemas are used to "fill in the gaps" when older adults experience memory failures (Castel, 2005; Hay & Jacoby, 1999; Umanath & Marsh, 2014), in that failures of underlying memory were a strong predictor and statistical mediator of age-related increases in schema effects on memory decisions. However, in contrast to predictions of these theories, older adults also exhibited slightly increased schema effects that could not be fully explained by age differences in underlying memory functioning in terms of discriminability, precision, or subjective strength. Moving beyond predictions of these extant accounts, we also found that age differences in schema effects on memory fundamentally differed depending on the type of memory involved: Age-related increases in schema bias were related to deficits in recollection-based memory, but not familiarity-based memory. Moreover, compared to younger adults, older adults had lower precision of recollection even when they did successfully recollect—irrespective of congruency—but this was not the case for familiarity. In fact, when controlling for encoding time, older adults had slightly *better* precision than younger adults within familiar scenes. Together, these results suggest that age-related increases in schema effects on memory are driven in large part by age-related decreases in recollection and the precision of recollected representations.

Overall, the present study provides strong support for theories that schema knowledge is compensatory or protective in aging by "filling in the gaps" of declining memory. That is, across all participants, poorer underlying memory discriminability predicted increased subject-level schema effects, and at a within-subjects level, participants exhibited more schema bias in scenes for which their underlying memory was weaker. Moreover, age increases in schema effects were statistically mediated by age increases in recollection failures, indicating that these two age-related cognitive changes may be fundamentally intertwined rather than independent. These findings are not currently well accounted for by theories that age differences in schema effects on memory are driven by inhibitory deficits: If effects were driven only by inhibitory deficits rather than deficits in underlying memory, then it is not clear why underlying memory failures would be strong predictors of schema bias, or why effects would vary between recollection and familiarity. These findings do not, however, preclude the possibility that both mechanisms are at play. That is, schema knowledge may primarily influence older adults' memory responses when that memory is unavailable or imprecise, but there may be additional inhibitory deficit effects wherein older adults are more likely to be inappropriately influenced by schemas even when their memory is otherwise strong. Our findings most strongly support this mixed account: Even though age differences in memory failure accounted for most age differences in schema effects, there was a small effect that could not solely be explained by memory failure. Specifically, schema effects were marginally larger in older adults even when their underlying memory representations were no less precise, accurate, or subjectively strong compared to younger adults' (i.e., within non-recollected scenes). It is possible that inhibitory deficits could explain this effect.

Our results can be characterized as providing strong, direct evidence for schema compensation accounts, as well as providing additional evidence that is indirect but consistent with explicit predictions of inhibition accounts (Lalla et al., 2022). However, in addition to inhibitory deficits, there are also alternative potential explanations for this latter evidence. One possibility is that older adults may adaptively rely more on schema knowledge as a general strategy, irrespective of underlying memory or failures of inhibition. It is possible that older adults come to habitually rely more on schema knowledge in a variety of domains (e.g., memory, attention, decision-making; Umanath & Marsh, 2014; Wynn et al., 2020) because it is often able to compensate successfully on occasions when other processes, such as memory, do fail. Supporting this general strategy interpretation, additional analyses revealed that older adults were more schema biased during initial search than were younger adults—such that the advantage of congruent over incongruent scenes for search speed was larger—before any memory effects could emerge, $p < .0001$. This is also supported by findings that older adults spend more time viewing congruent regions during search (Wynn et al., 2020). However, one could also attribute these effects to inhibitory deficits if one supposes that inhibition is needed to guide the eyes away from congruent regions. Future studies are needed to tease apart potential inhibition effects from potential general strategy effects.

In addition to addressing theoretical debates surrounding schema-memory interactions, our findings make novel empirical contributions to our understanding of age-related memory changes more broadly. Our findings on the role of precision are particularly relevant given emerging findings that aging primarily impacts the precision of memory, rather than the probability of remembering (Korkki et al., 2020; Nilakantan et al., 2018). In particular, we found that whether aging impairs memory precision critically depends on the type of memory examined. Whereas precision of recollection was notably impaired in older adults, the precision of familiarity was not impaired. In fact, when we controlled for encoding time, familiarity precision was slightly *better* in older than younger adults. Selective impairments in precision of recollection are well accounted for by prior work demonstrating that recollection reflects highly precise, hippocampus-supported representations, and that aging causes declines in hippocampal integrity (Bettio et al., 2017; Daselaar et al., 2006; Kolarik et al., 2018; Ramey et al., 2019; Yonelinas, 2002). In contrast, recent lesion work indicates that non-hippocampal memory representations, such as familiarity-based representations, produce more gist-like spatial memory for general regions (Kolarik et al., 2018)—and familiarity as well as the regions supporting it exhibit only minimal declines with age (Koen & Yonelinas, 2014; Rapp et al., 2002). Given that familiarity is thought to involve increased processing fluency and/or a sense of global match between a stimulus and internal representations (Bastin et al., 2019; Kelley & Rhodes, 2002; Norman & O'Reilly, 2003), it is possible that older adults are particularly adept at leveraging comparisons of fluency and/or global match when making spatial recall judgments. Future work is needed to determine whether the slightly better familiarity precision we found in older adults is robust; regardless, our findings strongly support a lack of age-related impairment in familiarity precision. (Note that "precision" in this case refers to the accuracy of the gist-like information supported by familiarity.) Moreover, these results indicate that future work on memory precision, both in general and in aging, should consider how effects may differ between recollection and familiarity. For example, it is likely that the paradigms used in these studies thus far, which generally involve forming associations between arbitrary features and objects (Korkki et al., 2020; Nilakantan et al., 2018), are primarily drawing on recollection-based memory. Therefore, current theories that healthy aging involves diffuse memory precision impairments may be overlooking spared precision within familiarity-based memory.

A related novel implication of the present study is that the underlying precision of representations, rather than simply whether or not a memory was retrieved at all, may play a role in schema effects on memory. Specifically, we found that even when older adults did recollect an old scene, their precision was lower across all congruency conditions and their schema effects were larger compared to younger adults. Moreover, age increases in schema bias were statistically mediated by age decreases in precision within recollected scenes (in addition to the likelihood of successfully recollecting at all). This suggests that the quality of older adults' recollection may be poorer, or perhaps less relevant to determinations of target location—and that schemas may fill in these gaps in otherwise strong memory. Interestingly, however, schema knowledge was not able to bring older adults' recollection precision to the level of younger adults, even for congruent information. Thus, another implication of these findings is that schema knowledge may not be able to fully compensate for age deficits in memory when highly precise memory is required rather than standard old/new judgments, given that schema knowledge is inherently more probabilistic and diffuse than episodic memory (Biederman, 1981; Huttenlocher et al., 1991; Torralba et al., 2006).

Further work is needed to determine the specific mechanisms driving the present effects. Experimental manipulations of memory would be particularly useful in further probing the relationship between schema bias and memory failure: for example, dividing attention in younger adults to produce levels of underlying memory that is similar to older adults, or examining how changing the value of encoded information could influence these dynamics (Schwartz et al., 2023; Siegel & Castel, 2018). In particular, because we did not manipulate recollection failures, causality is currently not established with respect to the relationship between schema bias and recollection failures, both in general and in the statistical mediation analysis of age effects. That is, it could be that recollection failures produce schema bias in aging, that schema bias produces recollection failures in aging, or that a third factor drives both effects. Our follow-up analyses suggest that the second possibility—schema bias impairing underlying memory—is unlikely, by showing that the age effects were not driven by congruency effects on search (encoding) time nor on subsequent recollection or familiarity estimates. However, it should be noted that fully disentangling memory from schemas at retrieval is likely not possible with current methods. It is therefore possible that our effects were influenced by other schema-memory interactions occurring during encoding that our additional analyses did not adequately control for. Regardless of whether the effects were purely related to retrieval, however, our results are directly in line with compensatory theories of schema effects in aging that would predict that underlying memory failures predict increased schema bias, and are not clearly accounted for by other extant theories. However, new mechanisms may be identified that point to a different causal direction, particularly in studies that manipulate memory.

In sum, the present findings suggest that we rely more on schema information as we age in order to compensate for increased memory failures and losses in memory fidelity. However, these findings also point to the possibility that additional active schema influences on memory may also increase with aging. Moreover, these findings highlight gaps in current theories of age-related schema effects on memory that warrant further investigation. Specifically, both the type of memory (i.e., recollection versus familiarity), and the precision of the underlying memory representations, appear to play an important role in determining whether older adults have increased schema effects on memory.

## Author note

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Authors declare no competing interests.

## CRediT authorship contribution statement

**Michelle M. Ramey:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Andrew P. Yonelinas:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **John M. Henderson:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization.

## Data availability

Data available upon request

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2024.105826.

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