

Effect of aging differs for memory of object identity and object position within a spatial context

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There has been considerable focus on investigating age-related memory changes in cognitively healthy older adults, in the absence of neurodegenerative disorders. Previous studies have reported age-related domain-specific changes in older adults, showing increased difficulty encoding and processing object information but minimal to no impairment in processing spatial information compared with younger adults. However, few of these studies have examined age-related changes in the encoding of concurrently presented object and spatial stimuli, specifically the integration of both spatial and nonspatial (object) information. To more closely resemble real-life memory encoding and the integration of both spatial and nonspatial information, the current study developed a new experimental paradigm with novel environments that allowed for the placement of different objects in different positions within the environment. The results show that older adults have decreased performance in recognizing changes of the object position within the spatial context but no significant differences in recognizing changes in the identity of the object within the spatial context compared with younger adults. These findings suggest there may be potential age-related differences in the mechanisms underlying the representations of complex environments and furthermore, the integration of spatial and nonspatial information may be differentially processed relative to independent and isolated representations of object and spatial information.

Advancing age is associated with changes in a number of cognitive domains (Erickson and Barnes 2003; Salthouse 2004; Craik and Bialystok 2006). Particularly age-related changes in episodic memory function have been frequently reported (Grady and Craik 2000; Craik and Bialystok 2006). In addition to a general decline in long-term retention, older adults show a reduced ability to differentiate between highly similar object representations (Yassa et al. 2011; Stark et al. 2013, 2015; Reagh et al. 2016; Berron et al. 2018) and object features (Yeung et al. 2017) compared with young adults. In contrast, spatial representations appear to be relatively spared (Fidalgo et al. 2016; Stark and Stark 2017) with older adults showing performance similar to young adults recognizing subtle changes in a spatial environment (Berron et al. 2018) and changes in the location of an object when presented on a blank screen (Reagh et al. 2016, 2018).

The dissociation and integration of object and spatial information has been a key question in memory research. Older adults show significant impairments in memory binding and maintaining associations despite having intact memory for the individual items (Chalfonte and Johnson 1996; Naveh-Benjamin 2000; Old and Naveh-Benjamin 2008). This is also observed in object-location binding with impairments in recalling the specific location of objects (Kessels et al. 2007; Berger-Mandelbaum and Magen 2019; Muffato et al. 2019) as well as recalling the identity of an object within an environment (Schiavetto et al. 2002; Kessels et al. 2007; Mazurek et al. 2015). The binding of object-location information has been hypothesized to involve the medial temporal lobes, including the hippocampus (Postma et al. 2008), although age-related changes in the prefrontal cortex, posterior neocortex and other regions have also been implicated in object location and object identity tasks (Schiavetto et al. 2002;

Meulenbroek et al. 2010). In the medial temporal lobes, the integration of object and spatial information is thought to arise from two parallel information processing streams (Eichenbaum 1999; Eichenbaum et al. 1999; Davachi 2006; Ranganath and Ritchey 2012; Knierim et al. 2013). One pathway, commonly referred to as the “what” pathway involves the perirhinal cortex and the lateral entorhinal cortex, and is thought to predominately process information about objects, items and events, while the “where” pathway involving the parahippocampal cortex and the medial entorhinal cortex is thought to process contextual and spatial information. Information from both pathways is projected to the hippocampus, which is then thought to integrate the spatial and nonspatial information into a cohesive “memory space” through a mechanism that is common to both object or episodic and spatial information (Eichenbaum et al. 1999).

However, emerging evidence suggests the processing of object and spatial information may be more integrated than previously thought with the lateral entorhinal cortex processing multimodal information, receiving both object and spatial information (Witter et al. 2017; Doan et al. 2019; Nilssen et al. 2019). In rodent studies, the lateral entorhinal cortex has been reported to be involved in the encoding of features from both the object and the environment (Deshmukh and Knierim 2011; Yoganarasimha et al. 2011; Deshmukh et al. 2012; Knierim et al. 2013). Rodent studies using single cell recordings in the lateral entorhinal cortex show that neurons in this region encode object-related information as well as spatial information about the object (e.g., position in relationship to the environment). These studies also show cells in the

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lateral entorhinal cortex that track the position of an object in the environment and do not fire when that object is no longer present (Deshmukh and Knierim 2011). A different subset of cells (“object trace cells”) have been reported to fire in previously experienced positions of an object within an environment (Deshmukh and Knierim 2011; Tsao et al. 2013). Lateral entorhinal cortex lesioned rodents show no impairment in performing an object-recognition task, but are impaired at recognizing spatial changes and object changes within a set of objects in an environment including position changes of the objects (Van Cauter et al. 2013) and previously learned object-place and object-context associations (Wilson et al. 2013a; Chao et al. 2016). Together, these findings suggest that, beyond encoding information about objects, the lateral entorhinal cortex encodes contextual information and may be binding non-spatial and spatial information, specifically encoding information about objects and certain spatial properties, including information about the object’s position within environment.

Few studies have examined the role of the lateral entorhinal cortex in encoding object identity, object position or changes to the spatial context in humans. Reagh and Yassa (2014) report that subtle perceptual differences between similar objects (e.g., two slightly different apples) elicits activity observed with functional magnetic resonance imaging (fMRI) in both the lateral entorhinal cortex and perirhinal cortex, while changes to an object’s position on a blank screen elicited activity in both the parahippocampal cortex and medial entorhinal cortex. Subsequent studies in older adults show impaired performance recalling the identity of object (Reagh and Yassa 2014; Stark and Stark 2017; Yeung et al. 2017; Berron et al. 2018; Reagh et al. 2018) but similar performance recalling position of the object on a screen compared with young adults (Reagh et al. 2016, 2018). However, these studies examined memory for object identity and object position on a blank screen, devoid of any spatial or contextual information. Given the findings from rodent studies, it appears that object identity and object position information are represented in relationship to the spatial environment in which they occur.

To examine the integration of nonspatial and spatial information, novel stimuli were developed to mimic real-life environments where objects could occur within the environment, more closely resembling animal studies in which rodents experience objects within an environment. A series of scenes were designed to have the same perspective, spatial dimensions and outdoor scenery (Fig. 1A). Scenes were classified into five general categories: living room, dining room, kitchen, bedroom, and office rooms to allow for the placement of categorically congruent furniture (Fig. 1B). Critically, within each scene, two to five different positions were defined that an object could logically occupy (Fig. 1C). The scene stimuli were first validated using mnemonic ratings and subsequently used in a novel object-in-context task to assess memory for object identity and object position in context and examine age-related changes in performance on this task in cognitively normal older adults compared with young adults.

Results

Stimulus validation

Results

To examine the mnemonic attributes of the indoor scenes, a stimulus validation study was conducted in which participants were asked to judge whether each scene was either “new” or “old.” A scene was correctly judged “new” if it was seen for the first time in the context of the task, and “old” if the exact scene was repeated once or twice (Fig. 2A). Participants correctly identified 67.9% of new trials as “new,” 76.1% of trials repeated once as old, and

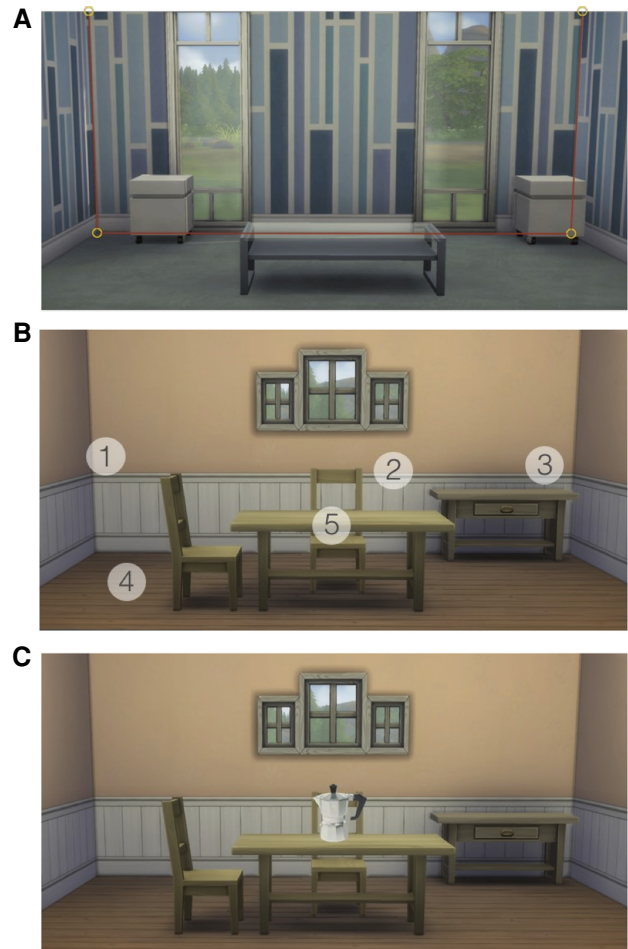


Figure 1. Task stimuli. (A) Scenes were designed to have identical dimensions and a similar perspective. (B) Scenes were designed to have two to five different positions where an object could be reasonably placed. Across all scenes, the same general positions were available for object placement. (C) Example of a scene with an object as seen by the participant. No object was present in the scenes for the stimulus validation study.

85.7% of trials presented twice as “old.” To compare the accuracy between scenes, the average accuracy for each scene was computed by collapsing the correct trial type responses across participants for each scene. This resulted in an average accuracy for each scene for trials presented once, trials repeated once, and trials repeated twice (Fig. 2B).

Of particular interest were the scenes judged “old,” as this would be most representative of how reliably identifiable and memorable each of the scenes were. Average accuracy for trials repeated once and correctly called “old” was used to compare the memorability of individual scenes. Scenes with accuracy scores between 60%–90% were selected for use in subsequent experiments, resulting in a total of 509 scenes.

Object-in-context experiment

In the Object Familiarization phase of the experiment, participants viewed images of everyday objects and were asked to rate the objects as either belonging “indoor” or “outdoor” to familiarize themselves with all objects (Fig. 3A). For the Object-in-Context phase of the experiment scenes were randomly selected from the

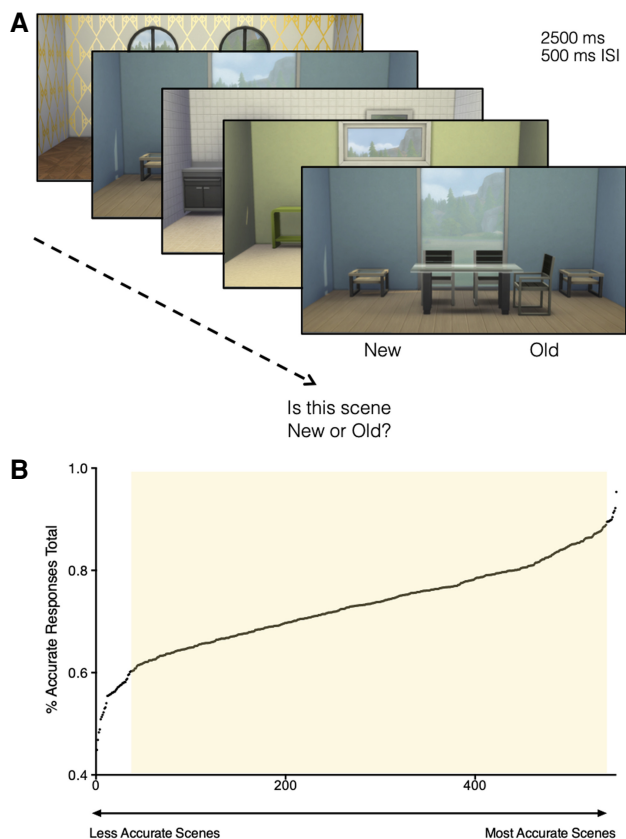


Figure 2. Stimulus validation. (A) Participants were presented with the scenes and asked to judge whether each scene was “New” (seen for the first time) or “Old” (a repeated scene). (B) Proportion of correct old responses to repeated scenes for each scene ranked from least to most often accurately recalled. Highlighted portion (60%–90% accuracy) of scenes was used in the subsequent experiment.

scenes validated in the stimulus validation study and an object from the Object Familiarization phase was presented within the scene (Fig. 3B). Trials consisted of “New” trials with new object and scene pairings that were presented once; “Repeat” trials with object and scene pairings that were presented and subsequently repeated once; “Identity Change” trials with object and scene pairings that were presented once and the object was changed to a nonsimilar different but categorically congruent object (i.e., different kitchen item in the kitchen environment) on the subsequent trial using the same scene; and “Position Change” trials with object and scene pairings that were presented once and the position of the object was changed in a subsequent trial using the same scene (Fig. 3C). Participants were asked to rate a scene and object pairing as “New” when they were not seen before in the context of the task, “Old” if the pairing was previously seen in the context of the task, or “Change” for a previously seen pairing where either the object or the location of the object was changed.

Demographic data and neuropsychological test performance is included in Table 1. Older adults were by criteria significantly older than young adults ($t_{(45)} = 47.54$, $P < 0.0001$) and completed significantly more years of education ($t_{(45)} = 6.84$, $P < 0.001$). During the experimental task, young adults correctly identified 82.71% (SD = 13.07%) of New trials while older adults correctly identified 62.83% (SD = 12.37%) of New trials (new object and scene pairing). For Repeat trials, where the same object and scene pairing are repeated, young adults correctly identified 82.40%

(SD = 10.65%) of trials while older adults correctly identified 76.46% (SD = 15.34%) of all trials. For Identity Change trials, with a new object and scene pairing, young adults correctly identified 66.56% (SD = 16.55%) of trials while older adults correctly identified 74.24% (SD = 16.07%) of trials. For Position Change trials, where the position of the object is changed, young adults correctly identified 80.36% (SD = 13.11%) of trials while older adults correctly identified 65.02% of trials (SD = 13.04%).

Task performance in older adults showed a significant effect of task condition ($F_{(3,18)} = 4.87$, $P = 0.01$) with significantly higher performance on Repeat trials compared with New trials ($t_{(18)} = 2.94$, $P < 0.01$) and Position Change trials ($t_{(18)} = 3.36$, $P < 0.001$), significantly lower performance on New trials compared with Identity Change trials ($t_{(18)} = 2.08$, $P = 0.03$), and significantly lower performance on Position Change trials compared with Identity Change trials ($t_{(18)} = 2.80$, $P < 0.01$). Young adults also showed a significant effect of task condition ($F_{(3,27)} = 9.52$, $P < 0.001$) with significantly lower performance on Identity Change trials compared with New trials ($t_{(27)} = 3.40$, $P < 0.01$), Repeat trials ($t_{(27)} = 4.31$, $P < 0.001$), and Position Change trials ($t_{(27)} = 3.28$, $P < 0.01$).

Older adults showed significantly poorer performance identifying new object-in-context trials (New trials: $t_{(45)} = 5.23$, $P < 0.001$) and trials in which the position of the object in the context was changed (Position Change trials: $t_{(45)} = 3.95$, $P < 0.001$) when compared with young adults. No significant differences were observed between young and older adults for trials in which the same object in context was repeated (Repeat trials: $t_{(45)} = 1.57$, $P = 0.12$) or in which the object in the context was changed (Identity Change trials: $t_{(45)} = 1.58$, $P = 0.12$) (Fig. 4).

A key goal of the current study was to examine the potential dissociation and age-related changes in memory for object position changes compared with object changes when presented in the context of a scene. A two-way analysis of variance comparing the Identity Change and Position Change trials between young and older adults showed no main effect of age ($F_{(1,45)} = 0.63$, $P = 0.43$) or condition ($F_{(1,45)} = 1.324$, $P = 0.26$). However, the analysis showed a significant interaction between age and condition ($F_{(1,45)} = 15.86$, $P < 0.001$), illustrating that older significantly less often correctly identified Position Change trials compared with young adults (Fig. 5A). A subsequent analysis of variance was conducted to examine the response rates of each response option (new, old, or change) for the Position Change and Identity Change conditions respectively. For the Identity Change trials, there was no significant interaction between young adults and old adults for the response type ($F_{(1,45)} = 0.49$, $P = 0.49$) (Fig. 5B). In contrast, for the Position Change trials, there was a significant interaction between young adults and older adults for the response type ($F_{(1,45)} = 19.20$, $P < 0.001$), showing that older adults significantly more often incorrectly identified those trials as “Old” and less often correctly identified those trials as “New” when compared with younger adults (Fig. 5C). As scenes were designed to have different positions where an object could reasonably be placed, each position change trial varied in the relative spatial distance of the change. To examine the potential effect of spatial distance in the Position Change trials, a two-way analysis of variance was used examining performance between young adults and older adults in the Position Change condition, contrasting trials with low spatial distance and high spatial distance. The spatial distance between object positions was calculated as the distance (in pixels) between all potential positions. Distances between the first position of an object and the changed position of the object in the second presentation ranged from 323 pixels to 1506 pixels. The spatial distance between the first and second presentation of the object was used to divide Position Change trials into low and high distance trials, roughly corresponding to position changes that were halfway across the spatial context and

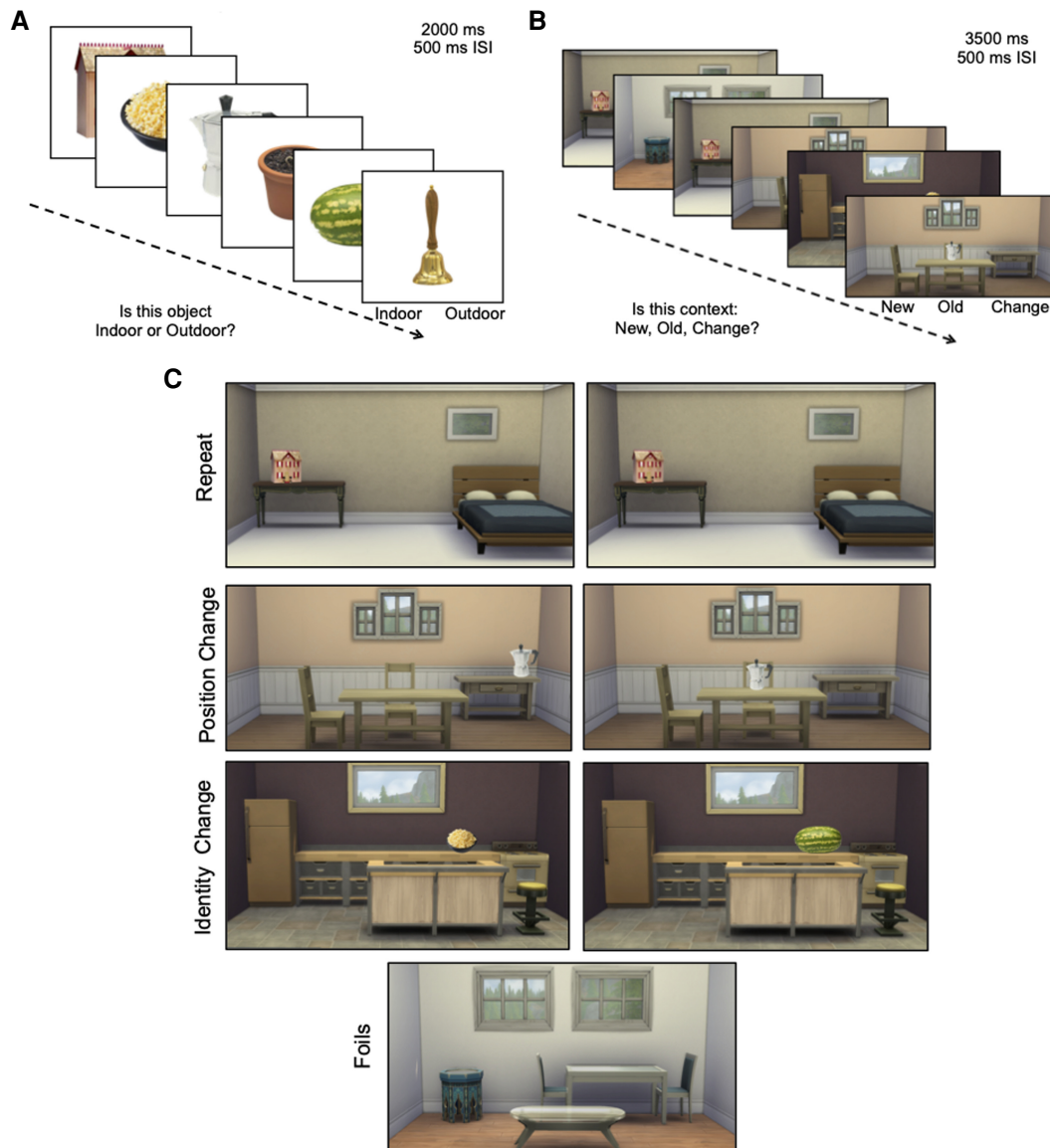


Figure 3. Object-in-Context task. (A) Participants were first presented with pictures of objects and asked to judge for each item if the object belongs “indoor” or “outdoor” to become familiar with the objects. (B) Participants were subsequently presented with the scene and object pairing and asked to judge for each if the scene was “New” (never seen before), “Old” (previously seen), or “Change” (resembled a previously shown scene and object pair). (C) Examples of repeat, position change, identity change, and foil stimuli.

across the entirety of the room. This analysis showed no main effect of distance in behavioral performance ($F_{(1,116)} = 1.47$, $P = 0.23$) and no interaction between age and distance ($F_{(1,116)} = 0.04$, $P = 0.84$).

Discussion

The goal of the current study was to assess age-related changes in memory for objects and their position in a scene. Using a novel task for viewing different environments (living rooms, bedrooms, kitchens, dining rooms, and office rooms), younger and older adults were asked to identify a change in the identity of objects, as well as the position of the objects. Older adults correctly identified a similar number of object changes in the scenes but identified significantly fewer object position changes compared with young adults. These findings expand upon previous studies examining

age-related differences reporting that older adults have difficulty recognizing changes in object identity (Yassa et al. 2011; Stark et al. 2013, 2015; Reagh et al. 2016; Olsen et al. 2017) and object features (Yeung et al. 2017) but not in recalling changes in the positions of an object when items were presented on a blank screen (Reagh et al. 2016, 2018). Studies examining age-related differences in memory for spatial information in scenes have reported mixed results with some reporting minimal age-related impairments in scene recognition (Fidalgo et al. 2016; Stark and Stark 2017) while others have reported no age-related differences (Berron et al. 2018, 2019). The majority of these studies examined object identity, scenes or an object’s position independently, without assessing the conjunctive encoding of an object and its position within a scene. However, mounting evidence suggests that object and position information, is encoded in relationship to the environmental context (Van Cauter et al. 2013; Wilson et al. 2013b; Chao et al. 2016).

Table 1. Demographics and clinical characterization of study participants

	Young adults		Older adults	
	Mean	SD	Mean	SD
Demographics				
Subjects	28		19	
Sex (M/F)	18/11		8/11	
Age (years)	19.26	0.94	65.11	5.00
Education (years)	13.89	1.1	17.11	2.11
Clinical dementia rating scale			0.0	
Clinical dementia sum of boxes			0.00	0.00
General cognition				
Clock drawing			23.05	2.12
MMSE			29.16	1.07
Memory				
Benton visual retention			7.11	1.20
BSRT immediate recall			52.8	7.89
BSRT delayed recall			9.11	2.00
LM immediate recall			51.05	7.29
LM delayed recall			32.58	6.56
Rey-O CFT immediate copy			32.84	2.55
Rey-O CFT delayed recall			18.74	4.45
Working memory				
Letter number sequencing			12.63	2.28
Executive functioning				
Stroop color word—word			96.32	16.20
Stroop color word—color			66.79	13.22
Stroop color word—color/word			40.33	8.35
Speed of processing				
Symbol-digit modalities test			48.68	9.18
Verbal fluency				
Verbal fluency (FAS)			47.37	15.45

(MMSE) Mini-mental status exam, (BSRT) Buschke selective reminding test, (LM) Wechsler logical memory test, (Rey-O CFT) Rey-Osterrieth complex figure test. All values are reported as standard raw scores and fall within the normal range based on population norms.

As noted in the background for the current investigation, in foraging rodents, cells in the lateral entorhinal cortex track the position of an object in the environment (Deshmukh and Knierim 2011) or the previous positions of an object within the environment (Tsao et al. 2013). Furthermore, a population-level analysis of neurons in the lateral entorhinal cortex shows that cells in this area encode for object, object position and context, and appear sensitive to encoding contextual information about the environment (Keene et al. 2016). These findings suggest that the representation of complex environments composed of the integration of spatial and nonspatial may be differentially processed relative to independent and isolated representations of objects and spatial information providing a potential explanation for the mixed results previously reported.

The task used in this study was designed to provide consistent spatial dimensions and perspective with objects congruent with the scene placed in plausible locations in the space. The scenes were equated for memorability based on ratings from a separate stimulus validation study in an effort to minimize the effects of novelty, perspective, congruence, and distance on recognition of object identity and object position. This task is similar to the approach used in a study by Yeung et al. (2019) showing that patients with cognitive decline are impaired in recognizing a change in the position of an object within a scene relative to cognitively normal older adults as measured by the proportion of eye fixations on a critical object in the environment. In Yeung et al. (2019) the authors manipulated the position of an object in the environment, and showed that the volume of the lateral entorhinal cortex was associated with memory for object identity but not for the object location within the environment in community dwelling older

adults. As in the current study, the integration of object information in a spatial context used by Yeung et al. (2019) required an initial study phase in which participants familiarized themselves with the objects used in the task.

In contrast, the task used by Reagh et al. (2018) featured an object mnemonic discrimination task without a study phase, requiring discrimination between highly similar and overlapping representations of either object identity or an object position on a blank screen without integration of spatial and nonspatial information. Berron et al. (2018) similarly used an object mnemonic discrimination task without a study phase using highly similar and overlapping representations of object identity, but examined memory for spatial information using scenes in which an element of the space itself was manipulated. Whereas the studies by Reagh et al. (2018) and Berron et al. (2018) reported no age-related differences in memory for spatial information, the Yeung et al. (2019) study reported impaired recognition of the position of an object in a scene consistent with the findings reported here. Additional studies are needed to determine whether age-related changes in memory for object position emerge in particular when an object is embedded in a scene or whether the processing of complex scenes itself is associated with age-related changes.

Despite the differences in the tasks used, the studies by Berron et al. (2018), Reagh et al. (2018), and Yeung et al. (2019) have observed selective engagement of the entorhinal cortex consistent with the findings from recording studies in animals. Changes to object identity have been associated with activation of the lateral entorhinal cortex (Berron et al. 2018; Reagh et al. 2016, 2018) while changes to the position of the object (Reagh et al. 2016, 2018) and context (Berron et al. 2018) have been shown to elicit activation in the medial entorhinal cortex. Additional studies using neuroimaging approaches in humans are needed to determine the mechanisms underlying the representations of complex environments and whether the integration of spatial and nonspatial information also engages the lateral or medial entorhinal cortex or may be differentially processed relative to independent and isolated representations of objects and spatial information.

Older adults showed significantly higher performance on the repeat trials compared with new and position change trials in the task consistent with a bias toward generalization observed in older adults (Stark et al. 2013) while young adults showed significantly lower performance on the Identity Change trials compared with

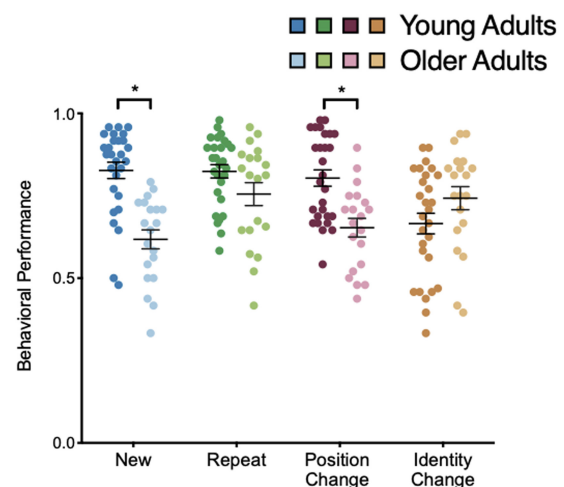


Figure 4. Behavioral performance in young and older adults. Older adults show impaired performance on Position Change trials and New trials relative to young adults. Bars represent mean \pm SEM. (*) $P < 0.05$.

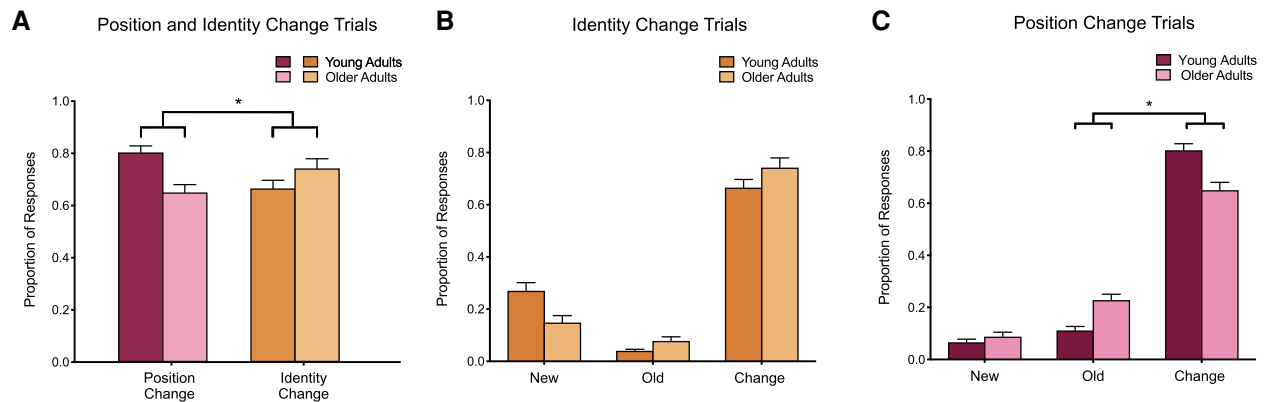


Figure 5. Older adults show impaired performance on Position Change but not Identity Change trials. (A) Older adults showed a significant impairment on Position trials relative to young adults but no significant difference on Identity Change trials. (B) Identity Change trials showed no significant difference in performance between older adults and young adults. (C) For Position Change trials, older adults more often incorrectly identified position change trials as “old,” instead of “change” compared with young adults. Bars represent mean \pm SEM. (*) $P < 0.05$.

New, Repeat, and Position Change trials. In addition to identifying significantly fewer position change trials compared with young adults, older adults also identified significantly fewer new scene and object pairings. This finding is consistent with reports of increased false recognition in older adults showing that older adults are more likely to falsely recall seeing words and pictures (Koutstaal and Schacter 1997; Norman and Schacter 1997; Dennis and Turney 2018) than younger adults (Devitt and Schacter 2016). Although increased false recognition in older adults has been well established, the mechanisms behind this phenomenon are not well understood and attributed to a general decline in prefrontal cortex integrity and connectivity between the prefrontal cortex and the medial temporal lobe (Devitt and Schacter 2016). In the data observed in this study, the observed difference in recognition memory between young and older adults does not appear to contribute to recognition memory for item level changes as age-related decline is only observed in the position change trials while performance on the identity change trials remains similar to young adults.

Within the medial temporal lobe (MTL), there has been an increased focus on the lateral entorhinal cortex in recent years due to the vulnerability of this region in both aging and Alzheimer’s disease (AD). The lateral entorhinal cortex is one of the first regions where tau neurofibrillary tangles, an established classic biomarker of AD, accumulates (Braak and Braak 1991; Lace et al. 2009; Jack et al. 2010), and subsequent neuronal degeneration and synaptic loss occurs (Hoesen et al. 1991; Gómez-Isla et al. 1996; Kordower et al. 2001; Selkoe 2002). In cognitively normal older adults, the lateral entorhinal cortex also shows considerable neurofibrillary tangle deposits compared with young adults (Braak and Braak 1991), suggesting that even in healthy aging, the structure and function of this region may be altered. Indeed, reduced volume of the lateral entorhinal cortex has been observed in older adults who perform lower on a test of general cognition and are at high risk for developing AD (Olsen et al. 2017; Yeung et al. 2017). Furthermore, hypoactivity of the lateral entorhinal cortex associated with poor object recognition has been observed in both older adults (Berron et al. 2018; Reagh et al. 2018) and in patients with amnesic mild cognitive impairment, a transitional stage between healthy aging and AD dementia (TT Tran, CL Speck, M Gallagher, et al., in prep.). Using novel stimuli consisting of objects positioned within a scene, the current study shows there may be potential age-related differences in the mechanisms underlying the representations of complex environments. Furthermore, the integration of spatial and nonspatial information may be differentially

processed relative to independent and isolated representations of objects and spatial information. It is possible that the integration of spatial and nonspatial information depends on the lateral entorhinal cortex and age-related changes are driven by the accumulation of pathology in this region in aging and AD. Further studies examining age-related changes and domain-specific processing are needed to determine the neural basis of information processing of these components in the medial temporal lobe.

Materials and Methods

Stimulus validation

Participants

A total of 181 Johns Hopkins undergraduate students (108 females; 73 males) contributed to the validation of the stimuli used in this study in exchange for course credit. Data from seventeen participants were removed from analysis due to inability or failure to complete the stimulus ratings while data from three participants were removed for a nonresponse rate $>20\%$ and data from four participants were removed for below chance accuracy. Complete data from 157 (90 females; 67 males, aged 18–22 yr old) participants were included in the final analysis of the scene ratings.

Materials and procedures

A total of 549 indoor scenes were created using the Sims 4 computer game (EA Games). All scenes were designed to have the same perspective, spatial dimensions and outdoor scenery. Scenes featured different types of windows, wallpaper, and flooring and included sparse furniture, including chairs, tables, sofas, and beds. Scenes were classified into five general categories: living room, dining room, kitchen, bedroom, and office rooms to allow for the placement of categorically congruent furniture. Critically, within each scene, two to five different positions were defined that an object could logically occupy. These general positions for object placement were consistent across scenes.

Participants were asked to judge whether each scene was either “new” or “old.” A scene was correctly judged “new” if it was seen for the first time in the context of the task, and “old” if the exact scene was repeated once or twice. A total of 182 scenes were presented once, 245 scenes were presented twice, and 122 scenes were presented three times in random order, with participants completing a total of 549 scenes. The scenes were rearranged between participants such that across all participants each scene was tested in each of the first presentation, first repeat and second repeat conditions.

Repeated stimuli were spaced apart a minimum of 15 trials and maximum of 40 trials between first, second and third presentations. Scenes were presented for 2500 msec with a 500 msec interstimulus interval. Stimuli were presented using Psychtoolbox 3 (Brainard 1997; Pelli 1997; Kleiner et al. 2007) using MATLAB (The Mathworks) on a Macintosh computer.

Object-in-Context experiment

Participants

Thirty-four young adults and 31 cognitively normal older adults were enrolled in the Object-in-Context experiment. Young adults were recruited from the undergraduate population at Johns Hopkins University and received course credit for their participation. Data from six young adult participants were excluded from analysis due to below chance performance ($n=4$) and incomplete data collection ($n=2$). Older adults were recruited from the community through flyers and online advertisements and were paid for their participation. Data from 12 older adult participants were excluded from analysis due to below chance performance ($n=11$) or incomplete data collection ($n=1$). This resulted in the analysis of data from a total of 28 young adults and 19 cognitively normal older adults in the Object-in-Context experiment (Table 1).

All older adult participants underwent medical, psychiatric, neurological, and neuropsychological evaluations and completed the Clinical Dementia Rating Scale (CDR; Morris 1993). Neuropsychological evaluation included the mini mental status exam (Folstein et al. 1975), the Buschke selective reminding test (Buschke and Fuld 1974), the logical memory subtest of the Wechsler memory scale (Wechsler 1987), the clock drawing test (Sunderland et al. 1989), the Rey-Osterrieth complex figure test (Rey 1941; Osterrieth 1944), and the Benton visual retention test (Benton 1974). Participants were excluded from further participation if they reported current neurological or psychiatric disorders, history of major head trauma, history of substance abuse or dependencies, or scored 2.5 standard deviations below published norms on one or more neuropsychological tests. All older adult participants had a global CDR and CDR-sum of noxes score of 0.

Materials and procedures

Stimuli consisted of 160 scene stimuli and 200 images of everyday objects. These scenes were randomly selected from the scenes validated in the stimulus validation study. Scenes were divided into five general categories: living room, dining room, kitchen, bedroom, or office rooms to allow for the placement of categorically relevant objects. All objects and scenes were categorically matched to allow congruency in the stimuli presentation (e.g., pencils in the office, apple in the kitchen).

Object familiarization phase

In the Object Familiarization phase of the experiment, participants viewed the 200 images of everyday objects and were asked to rate the objects as either belonging “Indoor” or “Outdoor” to familiarize themselves with all objects. Each object was presented on a blank screen for 2.5 sec with an interstimulus interval of 0.5 sec.

Object-in-Context phase

In the Object-in-Context phase of the experiment, participants completed 280 trials where an object from the Object Familiarization phase was presented within a scene. For each object-in-context trial, a scene was presented with a categorically appropriate object (e.g., blankets in a bedroom scene) for 3.5 sec with an interstimulus interval of 0.5 sec. Trials consisted of 40 “New” trials with new object and scene pairings that were presented once, 80 “Repeat” trials with 40 object and scene pairings that were presented and subsequently repeated once, 80 “Identity Change” trials with 40 object and scene pairings that were presented once and the object was changed to a nonsimilar different but categorically congruent object (i.e., different kitchen item in the

kitchen environment) on the subsequent trial using the same scene, and 80 “Position Change” trials with 40 object and scene pairings that were presented once and the position of the object was changed in a subsequent trial using the same scene. Participants were asked to rate a scene and object pairing as “New” when they were not seen before in the context of the task, “Old” if the pairing was previously seen in the context of the task, or “Change” for a previously seen pairing where either the object or the location of the object was changed. Repeated, Identity Change, and Position Change trials were spaced apart a minimum of three trials and a maximum of 12 trials with an average of eight trials between the first and second presentation.

Trials were presented in six different runs consisting of 70 trials per run. Runs were blocked so the first three runs would contain “New,” “Repeat,” and “Identity Change” trials while the last three runs would contain “New,” “Repeat,” and “Position Change” trials. This order was counterbalanced between participants. Participants were cued to the trial type at the beginning of each run. Previous versions of the task using no cues or a random order of trial types resulted in chance performance in older adults.

Stimuli were presented using Psychtoolbox 3 (Brainard 1997; Pelli 1997; Kleiner et al. 2007) using Matlab (The Mathworks) on a Macintosh computer.

Competing interests statement

M.G. is the founder of AgeneBio. M.G. and A.B. are inventors on Johns Hopkins University intellectual property with patents pending and licensed to AgeneBio. M.G. consults for the company and owns company stock, which is subject to certain restrictions under University policy. A.B. is a consultant for Acadia Pharmaceuticals, Inc. M.G. and A.B.’s role in the current study was in compliance with the conflict of interest policies of the Johns Hopkins School of Medicine.

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