

AGE-RELATED DIFFERENCES IN SPATIAL RELATIONAL PERCEPTION

BY

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Abstract

Deficits in episodic memory are prevalent in older adults (OA). Episodic memory involves binding event details to spatial contexts, thus, well-formed scene representations support memory for these associations. Furthermore, episodic memory and spatial processing share a neural underpinning: the hippocampus (HC). Episodic memory decline in aging is associated with HC degradation, suggesting a possibility that OA's memory deficits may arise from an inability to process coherent spatial representations due to HC degradation. Although OA show impairments in spatial cognition, it is unclear whether these occur during early stages of scene processing, i.e., visual perception. We present a novel study which investigated age differences in spatial relational perception. We predicted that OA would perform worse than younger adults (YA) at identifying changes in object location, but not object identity. Although results revealed no differences in accuracy, OA were significantly slower than YA when identifying changes in object location, and not identity. Our findings therefore support the hypothesis, revealing an age-related impairment in visuospatial relational perception. We posit that this is due to degradation of the HC, endorsing its role in scene perception. Further research into this age-related impairment may reveal important links between episodic memory and visuospatial perception.

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Age-Related Differences in Spatial Relational Perception

Try to remember a significant moment in your life, such as your first kiss, graduation ceremony, or a memorable day with friends. Chances are that an image has come to mind in which you can situate yourself and the surrounding context, such as the relevant people and objects. Remembering our personal experiences involves reimagining the spatial context in which they took place. Episodic memory, this ability to recall past experiences (Tulving, 2002), uses scenes as contexts in which event details can be bound together. Episodic memory and spatial processing are therefore intricately related: both relying on common neural structures and the formation of associations. What might happen to memory if the ability to accurately process scenes encountered in daily life is impaired? Memory deficits are prevalent in older adults (OA), however, the possibility that they originate from deficits in spatial perception remains largely unexplored. We present findings which address this possibility and propose a novel study to investigate older adults' ability to process spatial relations.

Older adults often struggle with memory, recalling details and sources of their memories less accurately (Balota et al., 2000; Murman, 2015; Nilsson, 2003). Although aspects of working memory and long-term memory also worsen with age, episodic memory in particular shows the most dramatic decline across adulthood (Silver et al., 2012). In memory tasks, older adults may remember specific items studied, yet contextual aspects such as the source of information tend to be less detailed and accurate (Balota et al., 2000). Indeed, episodic memory is highly dependent on linking event elements together within a greater context. Naveh-Benjamin and colleagues (2003) proposed that older adults' memory deficits are indicative of an inability to form associations between units of information, necessary for creating complex memories. Although older adults' memory for single items is similar to younger adults', their ability to recall pairs of items is significantly impaired, suggesting a deficit in associative processing.

Scenes and Episodic Memory

Memory for associations can be facilitated by visual scenes, as demonstrated in an associative inference paradigm by Robin and Olsen (2019). After studying sets of two images (composed of either an object, scene, and/or face), participants were given a cue and selected from two images which one the cue was paired with: either directly related

(previously paired), indirectly related (shares an associated image), or unrelated (previously seen but shared no association) to the cue. Memory was most accurate for objects that were associated with scenes. Further, participants identified more indirect relationships between pairs of items that were both associated to the same scene, demonstrating that associative inferences had been formed revolving around a common scene. The researchers interpret these findings as evidence that the mind treats scenes as spatial contexts to which objects can be easily bound and remembered as an imagined scenario.

Scenes are an integral component of episodic memory. They are believed to underlie recall of past experiences, thinking about the future, and imagining fictitious experiences (Hassabis & Maguire, 2007). Recalling a spatial context may therefore enable vivid mental imagery required for self-projecting into perspectives other than the one currently experienced. To demonstrate the importance of spatial context in memory for events, Robin and colleagues (2015) gave participants a brief written description of an event including either a person or place cue. Participants were instructed to imagine the event as vividly as possible. Upon cued recall, they remembered more events that were associated with a spatial cue and recollected these more vividly. Critically, even when recalling person-cued events, participants often reported remembering a location for the event, revealing that they spontaneously generated a spatial context that was initially absent. Altogether, these findings illustrate that scenes promote accurate and detailed memory for events, thereby highlighting their importance for episodic memory.

Memory and Spatial Perception in the Brain

Considering that spatial context is vital to episodic memory, it is plausible that memory deficits in this domain may be linked to spatial processing impairments. Interestingly, both mnemonic and spatial cognition have been attributed to function within a common brain region: the medial temporal lobe (MTL; Lee et al., 2012). The MTL is an ensemble of highly connected, yet functionally and anatomically distinct brain structures, including the hippocampus (HC; Squire et al., 2004). These structures form the basis of a long-term declarative memory system, crucial for the acquisition and retrieval of new knowledge (Squire & Zola-Morgan, 1991). By examining amnesic patients with MTL lesions, Scoville and Milner (1957) discovered that the degree of their

memory loss was positively correlated with the extent of damage to the HC. One of the most prominent cases of such amnesia was patient H.M., whose bilateral hippocampal removal left him completely unable to form new declarative memories (Scoville & Milner, 1957), while preserving the ability to acquire new skills despite no recollection of having the learned them (Cohen & Squire, 1980).

Although the MTL plays a critical role in long-term declarative memory, its function is not restricted to the mnemonic domain. In addition to severe memory loss, amnesic patients suffer specific perceptual deficits, suggesting a role of the MTL in visual perception. Its contribution is heterogeneous, with different structures specialized for processing different types of stimuli (Lee, Bussey, et al., 2005). Amnesic patients' performance on perceptual oddity judgement tasks by Lee et al. (2005) revealed that damage circumscribed to the HC impaired ability to discriminate between scenes, whereas broader MTL damage also affecting the perirhinal cortex (PRC) additionally impaired discrimination of objects and faces. Critically, these stimuli were presented simultaneously to minimize mnemonic demands. Similar studies involving healthy participants revealed greater hippocampal activity in response to scene compared to face oddity judgements. Coupled with knowledge that the HC is involved in certain aspects of spatial cognition (Lee et al., 2012), its connection to scene perception is not surprising

Importantly, the MTL seems to play a role at a late stage of visual perception. Perceptual deficits in amnesic patients are accentuated when dealing with complex, ambiguous stimuli that cannot be differentiated on the basis of a single feature (Barens et al., 2005; Lee, Bussey, et al., 2005). It is therefore proposed that the MTL is involved in high-level visual perception, housing complex conjunctions of simpler features. In patients with lesions limited to the HC, perceptual discrimination is unimpaired for objects, yet compromised for scenes (Lee, Buckley, et al., 2005). Scenes can be thought of as conjunctions of features or objects, bound into a spatial arrangement. Considering that hippocampal amnesia primarily impairs relational memory over item memory (Konkel et al., 2008), a parallel can be drawn between the HC's role in memory and perception, necessary for forging relations between units.

The Hippocampus and Scenes

There are several explanations for the HC's involvement in spatial perception. It

receives input from strong connections to both ventral and dorsal visual streams: responsible for processing objects and space, respectively (Lavenex & Amaral, 2000). The representational hierarchical model places the HC at the apex of the ventral visual stream, proposing that it forms conjunctions of objects processed in posterior brain regions into complex scenes (Lee et al., 2012). Brain imaging reveals increased HC activity related to constructing and maintaining mental representations of scenes, regardless of if they are perceived visually or imagined (Zeidman et al., 2015). The HC is also involved in extrapolating visual scenes beyond borders (Chadwick et al., 2013). Boundary extension (BE) is a rapid, robust phenomenon in which individuals remember seeing more from a scene than what was originally presented. When viewing a repeated image after a short interval, the BE effect leads neurologically intact individuals to judge that the second image appears closer, a phenomenon accompanied by increased HC activation. This effect is attenuated in HC-damaged patients (Maguire & Mullally, 2013), revealing a less expansive process of generating mental scenes from visual input when normal HC function is disrupted. Crucially, the HC is recruited even in situations that do not involve any mnemonic processing.

The HC appears to be involved in processing complex scene representations. Brain imaging in healthy young adults by Douglas and colleagues (2017) revealed greater HC activation in response to scene stimuli when these were structurally incoherent, hence requiring effortful binding of disparate spatial elements into a coherent representation. Likewise, McCormick et al. (2017) found that HC patients were impaired on a similar task. This suggests that the HC forms these complex representations and is recruited to bind associations between scene elements. Patients with damage to the HC are more impaired at discriminating between scenes presented from varying viewpoints (Lee et al., 2012), revealing an inability to configure the spatial relationships of multiple objects into a viewpoint-independent representation. Additionally, HC activity is associated with allocentric navigation (Moffat et al., 2006), in which viewpoint-independent representations of space are used to locate objects in relation to one another. Thus, it is proposed that a normally functioning HC extrapolates beyond visual information directly available to form expanded representations of scenes, ultimately enabling a seamless visual experience. Episodic memory may thus benefit from rich scene representations

generated by the HC to bind with event details, as scene construction theory suggests (Hassabis & Maguire, 2007).

Scene Perception and Episodic Memory

Given that episodic memory and spatial processing are interrelated, episodic memory deficits may arise from an inability to create and maintain complex scene representations, which would prevent linking event details to spatial contexts. If episodic thinking relies on scenes, HC damage would disrupt binding an event's disparate elements into memory. This view is supported by evidence that events without a spatial component are remembered in less detail (Robin et al., 2015) and that damage to the HC impairs episodic memory ability (Scoville & Milner, 1957). It is therefore plausible that episodic memory deficits may have origins in spatial perception.

Perceptual deficits in amnesia further elicit the possibility of such a connection between episodic memory and spatial perception, suitably rooted in the HC. Barense et al. (2012) propose that amnesic patients' memory may be compromised by their impoverished perceptual representations. Unable to bind lower-level features into complex representations, these patients exceedingly rely on feature-based processing. As the number of perceptually similar stimuli increases, their ability to process subsequent stimuli decreases due to interference. Further, their feature-based processing strategy becomes inefficient on tasks requiring holistic representations, such as spatial coherency or oddity judgement tasks. It is therefore conceivable that intact spatial perception facilitates the ability to create and recall episodic memories. Since many scenes encountered in daily life follow typical schemas, having accurate representations of these scenes would allow events to be encoded with their distinct, yet structurally similar spatial contexts, thus, promoting accurate memory.

The Aging Hippocampus

Although the severity of impairment is drastically different, hippocampal amnesia and healthy aging primarily affect the same domains of memory. Memory loss is also a common symptom in age-related diseases. Although cognitive decline is inevitable in aging, it can be accelerated by degenerative diseases such as dementia, Alzheimer's disease, and mild cognitive impairment (Murman, 2015). It is therefore important to delineate the extent of cognitive and neurological changes that occur within the healthy

aging process. A longitudinal study by Persson and colleagues (2012) assessed the structure and function of the MTL in healthy older adults during a 20-year span. Their study revealed that participants' age was negatively correlated with the volume of their HC. Despite individual differences in memory ability, participants whose memory declined over time also showed reduced activation in the HC between assessments. This latter finding was accompanied by over-recruitment of the parahippocampal gyri, (part of the dorsal visual stream; Squire et al., 2004) likely overcompensating for compromised HC function. Altogether, these findings provide a neural underpinning of memory decline in old age associated with the HC. Converging with amnesia studies, this suggests that older adults and amnesic patients may exhibit poorer performance in related domains when compared to healthy, younger populations. Visuospatial perception in amnesic patients has been studied extensively (Lee et al., 2012), however, it remains largely unexplored in older adults.

In addition to memory, older adults are impaired in certain aspects of spatial cognition. In navigation, OA struggle to learn routes and form cognitive maps (Moffat, 2009). They prefer egocentric processing strategies (Rodgers et al., 2012) using a self-centered reference frame, rather than allocentric (viewpoint independent) processing using an external reference frame. OA's navigation skills may therefore be compromised by their inability to generate allocentric representations of their environment. Supporting this idea, neuroimaging by Moffat et al. (2006) revealed that OA show less activation within the neural networks known to support allocentric navigation, particularly in the hippocampal region. Allocentric spatial memory is also affected in aging, as demonstrated in a task by Antonova and colleagues (2009) in which older adults less accurately remembered the position of a target in a virtual environment. Researchers suppose that OA's reliance on proximal cues, rather than the conjunction of multiple cues, impaired their performance on tasks with high allocentric processing demands. Interestingly, OA's spatial memory deficit was accompanied by reduced activity in the HC both at encoding and retrieval. Accordingly, age-related HC-dysfunction and its accompanied shift towards egocentric processing may underlie impairments on tasks in which allocentric processing is required.

Further, spatial memory is affected in older adults. Spatial memory is believed to

comprise various HC-dependent processes. Clark et al. (2017) revealed that older adults performed particularly worse than younger adults in spatial relational tasks, but not in pattern separation tasks. Pattern separation entails encoding distinct spatial locations, whereas relational processing refers to associations between such spatial locations. The same selective impairment was observed in patients with HC damage (Watson et al., 2013), implicating the HC in memory for spatial relations. The key finding here is that although location of a single item can be recalled accurately, these individuals misrepresent the spatial configuration of multiple items in relation to each other. This furthers evidence of the HC's importance in associative processing, extending to spatial processing for building mental representations of complex scenes.

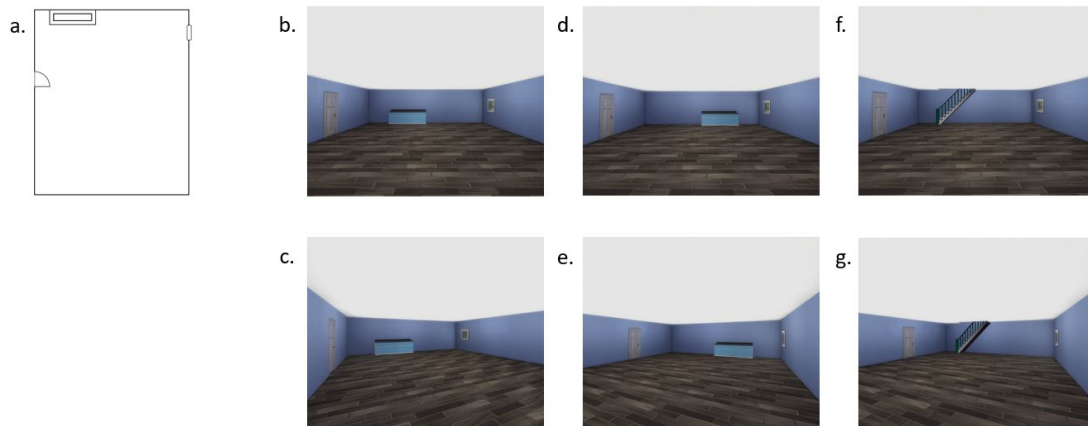
The Current Study

Memory deficits in older adults are well-studied, however, the possibility that these arise from deficiencies in visuospatial perception remains largely unexplored. Although various aspects of spatial cognition are affected in old age, whether these impairments occur at the time of visual perception or later on during mnemonic processing is unknown. The present study investigated age differences in visuospatial relational perception. In a task with few mnemonic demands, we attempted to clarify whether OA exhibit spatial processing deficits in perception, isolated from other shortcomings in memory. Crucially, our task is designed to investigate spatial relational perception in order to exercise the conjunctive nature of the HC's role in scene perception.

We report findings from a novel study in which participants compared 2-dimensional (2D) floor plans to 3-dimensional (3D) virtual rooms (see Figure 1), identifying whether the objects within them correspond in identity and location. Furthermore, we manipulated the viewpoint from which virtual rooms were presented in order to emphasize allocentric representational demands. This specific design allowed us to directly contrast participants' perception of objects and spatial relations. Both types of trial (object and location change) employ the same stimuli and instructions yet require different types of processing. In object change trials, participants compare floor plans to rooms in which a single element has a different identity. In location trials, a single element's position differs between the floor plan and room. This task therefore contrasted

Figure 1

Examples from the Main Task.



Note. Paired with the floor plan (a), scenes (b, c) are matches, scenes (d, e) are location mismatches, and scenes (f, g) are identity mismatches. Scenes (b, d, f) are presented from a center viewpoint, and scenes (c, e, g) are presented from an off-centre viewpoint. perception of objects versus the spatial relationships between them.

We hypothesized that age would negatively influence the ability to identify changes in the spatial relations between scene elements, but not changes in objects' identities. Given that the HC degrades in function with age (Persson et al., 2012), and that it is involved in processing spatial relationships between items, we anticipated that older adults would perform worse than younger adults on location change trials. We did not expect age differences on object change trials, as no such involvement of the HC nor healthy aging has been attributed to deficits in object perception.

The results of this study may help to elucidate OAs' episodic memory deficits by revealing a primary deficit in spatial relational perception. Such findings would complement the notion that scenes are integral to episodic memory, and further our current understanding of the role of the hippocampus in visual perception and memory.

Method

Participants

Participants were recruited online via Prolific Academic (<https://www.prolific.co>). We recruited older adults between the ages of 60 and 85 years, and younger adults

between the ages of 18 and 35 years. Six participants were screened out during the study due to low performance on the training tasks (more than 96 incorrect trials) or the main task (more than 50 invalid trials), and one due to a technical error. Five participants completed the study but were excluded from analysis due to very poor performance: three for high error rates on either training task ($z > 3$), one for low overall accuracy on the main task ($z > 3$), and one for not responding on a large number of trials ($z = 2.88$).

The remaining participants were 11 older adults ($M_{age} = 63.18, SD = 3.43$) and 14 younger adults ($M_{age} = 25.29, SD = 5.36$). All participants were fluent English speakers, had normal-to-corrected vision, and resided in Canada. There were 11 men and 14 women. Twenty-two participants were right-handed and three were left-handed. The average number of years of education participants had completed since first grade was 16.18 ($SD = 2.36$) for older adults, and 15.57 ($SD = 2.84$) for younger adults. This was not significantly different between groups, $t(23), p = .573$.

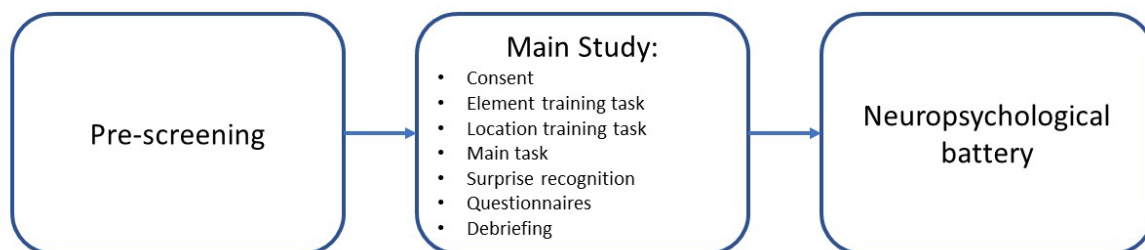
Participants were screened to ensure no diagnosis of a neurological or psychological disorder, current use of medication known to affect memory, nor previous head trauma resulting in the loss of consciousness for more than a few seconds. Participants were compensated at a rate of \$2.50 (CAD) per 15 minutes of participation. On average, participation lasted 75 minutes and participants were remunerated \$12.50.

Materials

The study was programmed using Version 6.1.0 of JSPsych (de Leeuw, 2015) and was administered online via Pavlovia (<https://pavlovia.org>). Participants completed the study on their own computer. A calibration task at the beginning of the study session ensured that the display area scaled to 25.4 cm wide and 16.93 cm high, regardless of the participant's monitor size or screen resolution.

Overall Procedure

Participants were informed about the nature of the study prior to giving informed consent (Appendix A). An overview of the procedure is presented in Figure 2. Participants completed a short pre-screening questionnaire (Appendix B) including demographic and health-related questions to verify eligibility. Eligible participants were then invited to participate in the main study session. Participants were randomly assigned to one of 16 conditions, counterbalanced across the trial order and keys used to respond in

Figure 2*Overall procedure.*

Note. Participation in the neuropsychological battery took place between one day and 8 weeks following completion of the main study.

the task. The study session proceeded as follows: element training task, location training task, main task, surprise recognition task, and questionnaires. Participants were then provided the opportunity to leave any comments or questions for the researchers about their experience in the study or any issues encountered. Finally, participants were debriefed (Appendix C) and thanked for their participation. The main study session took approximately 75 minutes to complete. Following successful completion of the main study session, participants were invited to complete the neuropsychological battery session. Participants completed the battery at least one day following the main study session.

Stimuli

In each trial within the training tasks and main task, an image of a floor plan and a room was presented simultaneously. In some cases, these depicted the exact same scene configuration. In other cases, the scenes differed in a single aspect: either an object's identity or location. Floor plans were simple layouts of a room presented from a bird's eye view. These floor plans were created using Adobe Photoshop (version 2020, 21.0; Adobe Systems, San Jose, California). Rooms were virtual 3D rooms created on The Sims 4 (version 1.56.52.1020; Electronic Arts, Redwood City, California). The floor plans and rooms contained real-world scene elements: represented by flat symbols or 3D objects, respectively. The four possible scene elements were doors, stairs, windows, and counters. In the rooms, elements could be represented in various colour and pattern forms, with a total of 24 unique versions of each scene element across scenes.

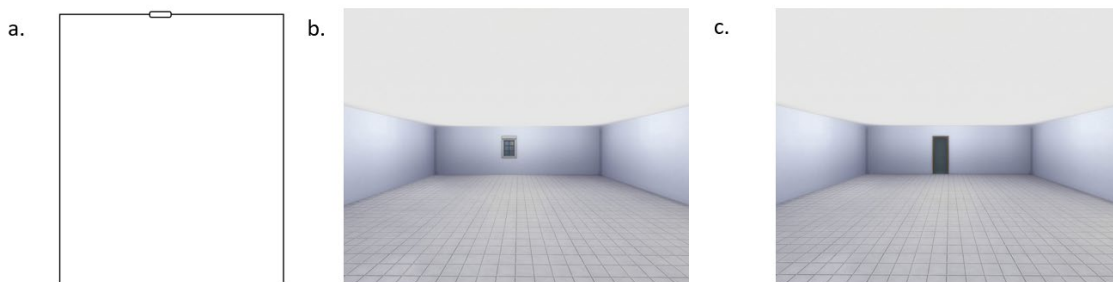
Element Training

Stimuli. Participants first learned to identify and differentiate the scene elements. Scenes contained a single element at the same location in both the floor plan and the room (Figure 3). Each 3D version of each scene element was presented for a total of 96 trials (4 elements x 24 versions). On half of the trials, the element in the floor plan and the room had the same identity (“matched”; see Figure 3 b), whereas in the other half, they did not have the same identity (“mismatch”; see Figure 3 c).

Procedure. Participants were instructed to respond “yes” or “no” to the question “Does the floor plan match the room?” using the “F” and “J” keys on their keyboard. Participants were first shown examples of matches and mismatches for each element (Figure 3), then began the training task. Trials ended either immediately after a response was given, or after 5,500 ms. Feedback on trial performance (“Correct” or “Incorrect”) was then displayed for 500 ms. Consecutive trials were preceded by an inter-stimulus interval of 1,000 ms. Incorrect trials were repeated at the end of the task until the correct response was given. If a participant repeated more than 96 trials, the session ended prematurely and the participant’s data was excluded from analysis.

Figure 3

Examples from the Element Training Task.



Note. Paired with the floor plan (a), scene (b) is a match as it also contains a window, and scene (c) is a mismatch as it instead contains a door.

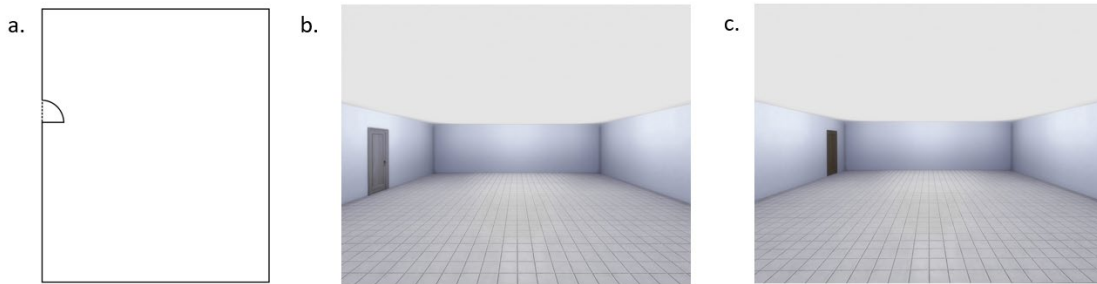
Location Training

Stimuli. Participants next learned to identify location changes between a floor plan and a room. Scenes contained a single element of the same identity (Figure 4). On half of the trials, the element’s location was the same in both the floor plan and the room (“match”; see Figure 4 b), whereas on the other half of trials, it differed (“mismatch”; see

Figure 4 c). Each version of each scene element was presented for a total of 96 trials (4 elements x 24 versions). This task also introduced the viewpoint manipulation: on half of the trials, the room was presented from a centered perspective. The remaining trials were split evenly between left and right perspectives.

Figure 4

Examples from the Location Training Task.



Note. Paired with the floor plan (a), scene (b) is a match, and scene (c) is a mismatch as the door is closer to the wall.

Procedure. Participants were instructed to respond “yes” or “no” to the question “Does the floor plan match the room?” using the “F” and “J” keys on their keyboard. Participants were first shown examples of location matches and mismatches (Figure 3), then began the training task. Trials ended either immediately after a response was given, or after 5,500 ms. Feedback on trial performance (“Correct” or “Incorrect”) was then displayed for 500 ms. Consecutive trials were preceded by an inter-stimulus interval of 1,000 ms. Incorrect trials were repeated at the end of the task until the correct response was given. If a participant repeated more than 96 trials, the session ended pre-emptively and the participant’s data was excluded from analysis.

Main Task

Stimuli. Participants completed 288 trials in the main task. For each trial, participants were shown scenes containing three distinct elements (Figure 1). On half of the trials, the scene configuration in the floor plan and the room corresponded in all aspects (“match”; see Figure 1 b, c). Of the remaining half of trials, scenes differed in a single aspect. In half of these (respectively one quarter of all trials), one of the elements in the room was different than the element in its corresponding position in the floor plan (“object change”; see Figure 1 f, g). In the other half, one of the elements was at a

different location in the room than it was in the floor plan (“location change”; see Figure 1 d, e). An example of each type of trial scene is presented in Figure 1. On object change trials, the mismatching elements were necessarily of the same width, such that only doors and windows, or counters and stairs were swapped for one another. The viewpoint perspective from which rooms were presented varied across trials. On half of the trials, rooms were presented from a central perspective that aligned with the floor plan. In the remaining half of trials, rooms were either presented from an off-centre viewpoint that did not align with the floorplan, with one quarter of rooms presented from the left and right, each.

Procedure. Participants were instructed to respond to the question “Does the floor plan match the room?” using the “F” and “J” keys on their keyboard. Participants were first shown examples of location matches and mismatches (Figure 1). Trials ended after 5,500 ms, regardless of whether a response was given. A fixation cross was then presented for 500 ms. Consecutive trials were preceded by an inter-stimulus interval of 1,000 ms. Participants were instructed to respond as quickly and as accurately as possible. Response time and accuracy were recorded for each trial. If a participant had more than 50 invalid trials (either responded before stimuli appeared on the screen, or did not respond at all), the session ended pre-emptively and the participant’s data was excluded from analysis. Participants could take a break every 72 trials.

Design. A full factorial 3 (scene type: match, object change, location change) x 2 (viewpoint: center, off-centre) design was implemented. Scene type and viewpoint were counterbalanced both within and between subjects. For each given floor plan, participants in half of the counterbalance conditions saw it paired to a matching room, while the other half saw it in a mismatch trial (one quarter in object and location change, respectively). Further, half of participants saw the room from the center viewpoint, whereas the other half saw it from an off-centre viewpoint (one quarter from the left and right, respectively). Importantly, all participants saw the same 288 floor plans, but the room and corresponding type of trial to which it was paired varied based on their counterbalance condition.

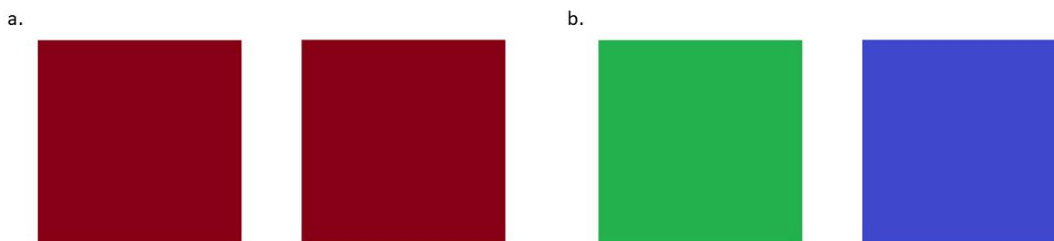
Attention Checks

Eleven attention checks were dispersed evenly throughout the main task. These

were simple color-matching tests (Figure 5) in which participants were instructed to respond to the question “Are the squares the same colour?” using the “F” and “J” keys on their keyboard. Participants’ final attention score was calculated as the proportion of attention trials they answered correctly.

Figure 5

Example Attention Check trials.



Note. Participants used the same keys as in main trials to indicate whether or not the stimuli match. In a), the squares match since they are both the same colour. In b), the squares do not match since they are not the same colour.

Surprise Recognition Task

Participants were presented with a floor plan containing a single element and were asked to type the name of the real-life object it represents. This was repeated for all four of the scene elements. This was included to verify participants’ attention and comprehension of the experimental task.

Questionnaires

All participants completed three questionnaires. The Survey of Autobiographical Memory (Appendix D; Palombo et al., 2013) consists of 26 statements to which participants rate the strength of their agreement on a 5-point Likert scale, ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). The Verbalizer-Visualizer Questionnaire (Appendix E; Richardson, 1977) consists of 30 true or false questions. The Vividness of Mental Imagery Questionnaire (Appendix F; Marks, 1973) consists of 16 prompts to which participants rate the vividness of their mental imagery on a 5-point Likert scale, ranging from 1 (*perfectly clear and as vivid as normal vision*) to 5 (*no image at all, you only “know” you are thinking of an object*).

Additionally, older adults also completed the Memory Functioning Questionnaire (Appendix D; Gilewski et al., 1990), which consists of 64 items to which participants rate the quality of their memory on a 7-point Likert scale.

Neuropsychological Battery

Participants also completed a custom battery of neuropsychological tasks in a separate session to assess their cognitive abilities. The battery mimicked standard neuropsychological batteries such as the “Cambridge Cognition test battery for Alzheimer’s disease” and the “Repeatable Battery for the Assessment of Neuropsychological Status”. Each task required responding to neutral stimuli: either verbal or visual, using a mouse, keyboard, or voice. The results of this battery are beyond the scope of this paper.

Analyses

Participants’ data were cleaned to remove outlier trials. This was achieved by iteratively removing all trials in which response time fell more than 3 standard deviations from the individual’s mean, repeating this procedure until no outliers remained. Accuracy was operationally defined as the proportion of correct trials within a condition. Mean response time (RT) was averaged over all correct trials within a condition.

Analyses in the present study are limited to results of the main task and the primary hypothesis regarding interaction of age and scene type. A 2x2x3 mixed factor repeated measures analysis of variance (ANOVA) was conducted to compare the effects of age (young, old), viewpoint (center, off-centre), and scene type (match, object change, location change) on each measure of task performance (accuracy and RT). Mauchly’s test of sphericity was conducted to test for homogeneity of variance before each ANOVA test, and Greenhouse-Geisser corrected p values and degrees of freedom are reported where sphericity was not assumed. All significant effects were followed up with pairwise comparisons using Bonferroni-adjusted p values to maintain a family-wise alpha level of .05.

We had no specific predictions regarding match trials; rather, these served as a neutral control condition. Therefore, it was useful to conduct a separate test directly comparing object and location change trials to increase our ability to detect any effect between conditions of interest. We conducted a planned 2x2 ANOVA to compare the

effects of age and scene type, restricted to object and location change trials. Finally, pairwise comparisons were conducted to directly investigate our a priori hypotheses, using Bonferroni adjusted p values to maintain a family-wise alpha level of .05. Separate analyses were conducted for each measure of performance (RT and accuracy) as the dependent variable.

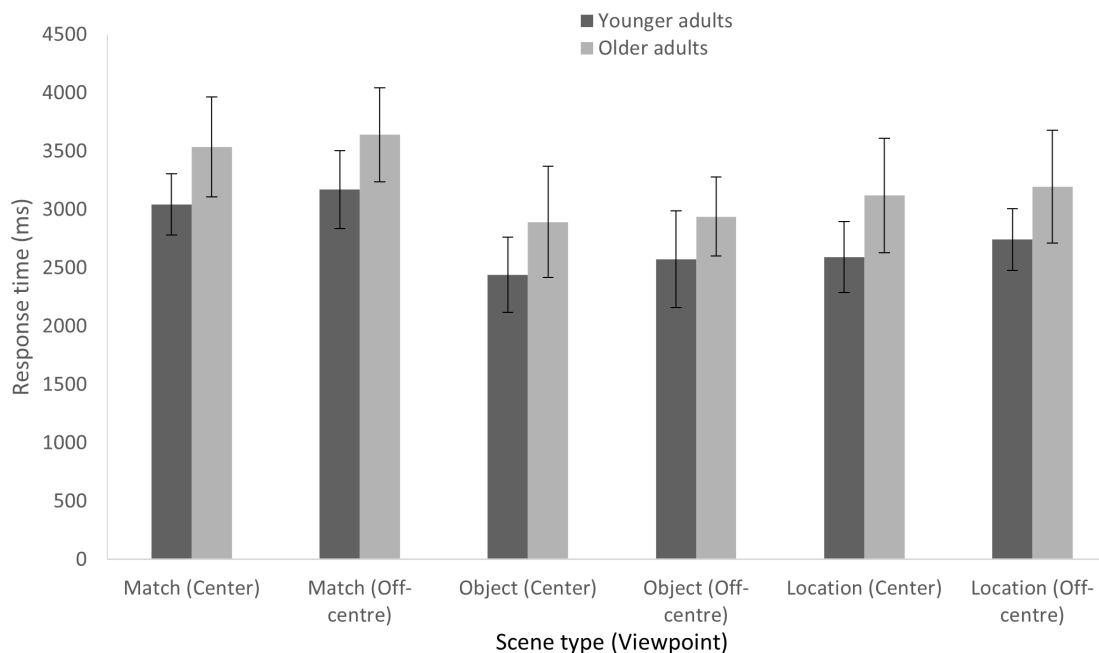
Results

Reaction Time

A 2x2x3 repeated measures ANOVA was conducted to investigate the effects of age, viewpoint, and scene type on reaction time (Figure 6). There were significant main effects of scene type, $F(2, 46) = 155.973, p < .001, \eta^2 = .871$; viewpoint, $F(1, 23) = 16.445, p < .001, \eta^2 = .417$; and age, $F(1, 23) = 10.903, p = .003, \eta^2 = .322$. The ANOVA did not reveal any significant interactions between factors. RT was significantly longer for older compared to younger adults, and for off-centre compared to center viewpoints.

Figure 6

Response time by scene type, viewpoint, and age.



Post-hoc tests revealed all scene types were significantly different from one another: match trials were significantly longer than location change trials, $t(24) = 13.115, p < .001, d = 2.623$; and object change trials, $t(24) = 17.881, p < .001, d = 3.576$; and

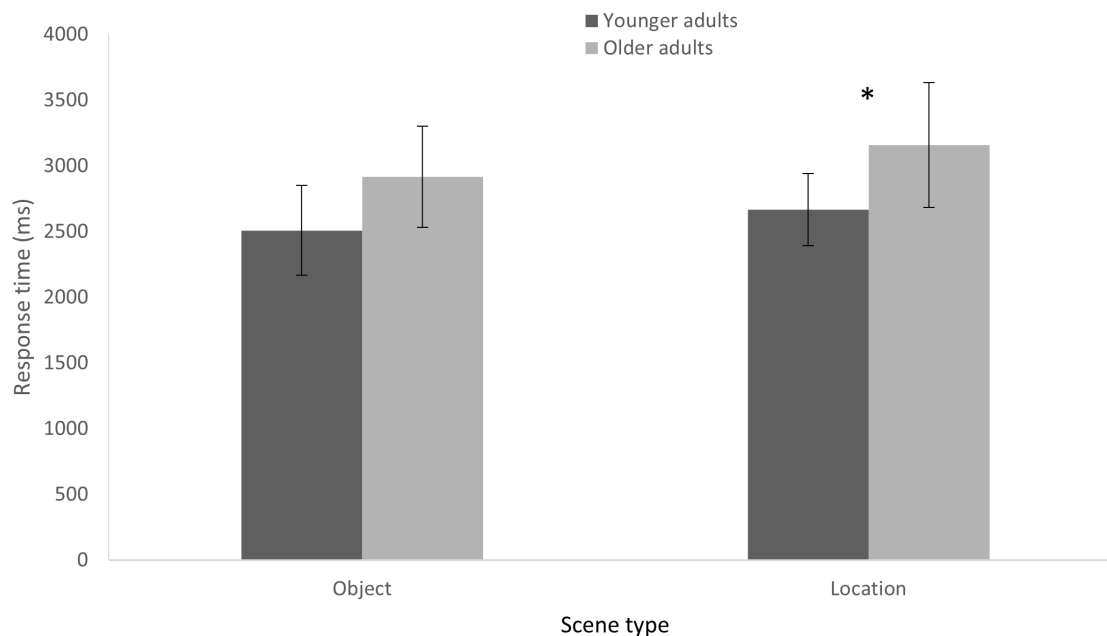
location change trials were significantly longer than object change trials, $t(24) = -4.868$, $p < .001$, $d = -0.9735$.

Planned comparisons

Interaction between age and scene type. A 2x2 repeated measures ANOVA was conducted to investigate interaction effects between age and scene type on reaction time (Figure 7). The ANOVA revealed a significant main effect of scene type, $F(1, 23) = 24.629$, $p < .001$, $\eta^2 = .517$; and age, $F(1, 23) = 9.948$, $p = .004$, $\eta^2 = .302$. There was no significant interaction between age and scene type, $F(1, 23) = 1.064$, $p = .313$, $\eta^2 = .044$. Planned pairwise comparisons revealed longer RT for older compared to younger adults on location change trials, $t(23) = 3.257$, $p = .024$, $d = 3.257$; but not object change trials, $t(23) = 2.809$, $p = .070$, $d = 2.809$. RT for location trials was significantly longer than object trials in younger adults, $t(13) = -4.250$, $p = .007$, $d = -1.136$; but not both older adults, $t(10) = -3.101$, $p = .079$, $d = 0.935$.

Figure 7

Response time by scene type and age.



Note. Age-differences were significant on location trials, * $p < .05$.

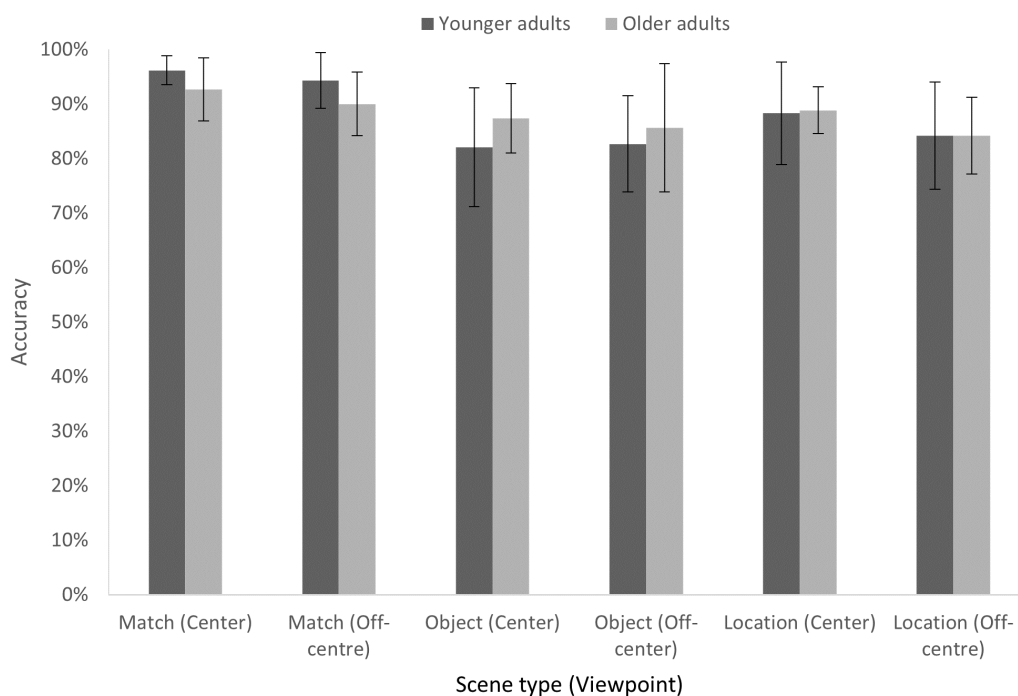
Accuracy

A 2x2x3 repeated measures ANOVA was conducted to investigate the effects of

age, viewpoint, and scene type on accuracy (Figure 8). There were significant main effects of scene type, $F(2, 46) = 12.467, p < .001, \eta^2 = .352$; viewpoint, $F(1, 23) = 9.800, p = .005, \eta^2 = .299$; but not age, $F(1, 23) = .008, p = .931, \eta^2 = .000$. The ANOVA did not reveal any significant interactions between factors. Accuracy was significantly higher for center viewpoints compared to off-centre.

Figure 8

Accuracy by scene type, viewpoint, and age.



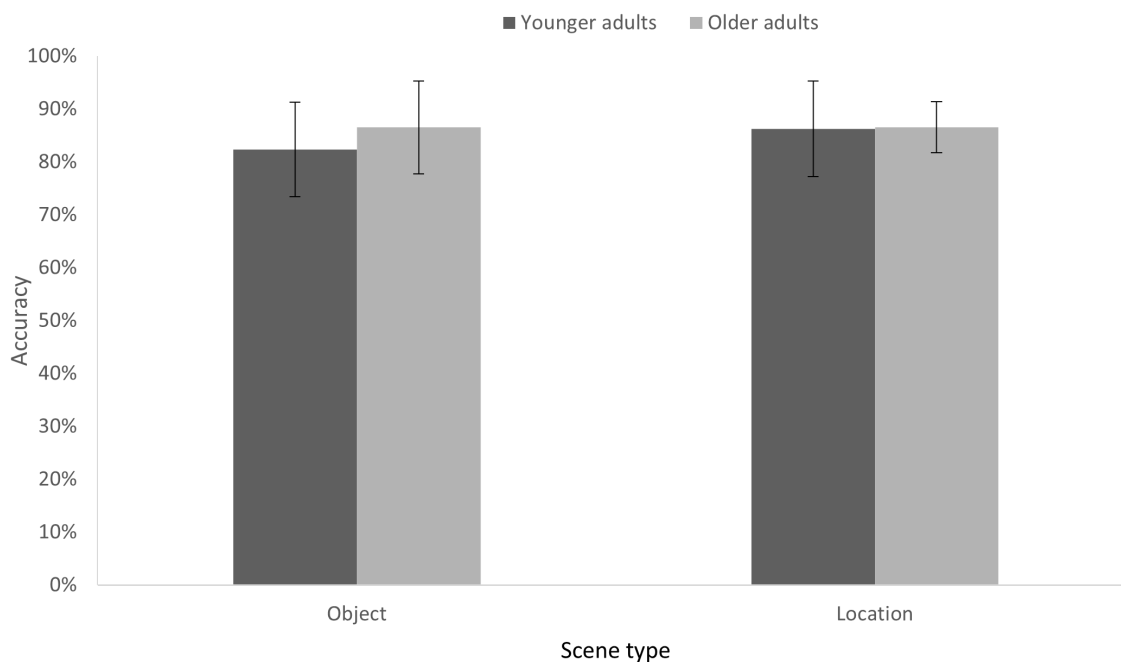
Post-hoc tests revealed accuracy was higher for match trials compared to object change, $t(24) = 4.760, p = .001, d = 0.952$; and location change trials, $t(24) = 4.079, p = .003, d = 0.816$. Accuracy for object and location change trials were not significantly different, $t(24) = -1.109, p = 1.948, d = -0.222$.

Planned comparisons

Interaction between age and scene type. A 2x2 repeated measures ANOVA was conducted to investigate interaction effects between age and scene type on accuracy (Figure 9). The ANOVA revealed no significant main effects of scene type, $F(1, 23) = 0.968, p < .335, \eta^2 = .040$; nor age, $F(1, 23) = 0.696, p = .413, \eta^2 = .029$. There was no

Figure 9

Accuracy by scene type and age.



significant interaction between age and scene type, $F(1, 23) = 0.928$, $p = .345$, $\eta^2 = .039$.

Planned pairwise comparisons revealed no difference in accuracy between older and younger adults on object change trials, $t(23) = 1.155$, $p = 1.82$, $d = 1.155$, and location change trials, $t(23) = 0.073$, $p = 1.844$, $d = 0.099$. There was no significant difference in accuracy between object and location trials for older adults, $t(10) = -0.015$, $p = 6.917$, $d = -0.005$; nor for younger adults, $t(13) = -1.373$, $p = 1.351$, $d = -0.367$.

Discussion

In the present study, we examined whether there are age differences in the ability to process visuospatial relations. Using a novel floor plan task, we compared older and younger adults' ability to perceive changes in object location and identity. First, we hypothesized that older adults would perform worse than younger adults on location change trials, but not on object change trials. Although there were no age differences in performance accuracy across scene types, reaction time differed. Older adults were significantly slower than younger adults on location change trials, but not object change trials. It is worth noting that there may have been a subtle effect of age on object trials, given that the statistical difference only reached insignificance after Bonferroni corrections. Our results therefore partially support our prediction that older adults would

be selectively impaired at processing visuospatial relations and not object identities. Nonetheless, the effect size of age was greater on location compared to object change trials. Therefore, the overall pattern of our results align with our predictions, and encourage further research into the effects of age on spatial relational perception.

Representational Demands

Our study was designed to recruit hippocampal function by emphasizing the need for flexible and coherent spatial representations, as demonstrated by previous studies (Douglas et al., 2017; Lee et al., 2012; Zeidman et al., 2015) . In our study, participants compared a 2-dimensional bird's eye-view floorplan to a 3-dimensional room and judged whether these depicted the same scene configuration. The task therefore required that participants generate a mental representation of both images in which they could directly compare the scene elements and their locations. When an object differed between the images (object change), the mismatch could be identified by comparing all scene elements one at a time, based on their ordinal position. Changes in object location, however, required different mechanisms to correctly identify. Participants had to use distance cues between scene elements to resolve an object's location, then use this to compare locations in the floor plan and virtual room. Participants therefore required a flexible and accurate representation of the spatial relations encoded in both images. In agreement with our predictions, we found that OA were selectively impaired at location change trials, and not object change trials.

Given the main effect of age, older adults were also generally slower on all scene types, which may be indicative of a general deceleration of cognitive processes due to age (Murman, 2015). Additionally, since all scene types required some form of scene representations, it is plausible that the HC was recruited to form such scene representations, and accordingly, was less efficient in OA. However, given that age had a greater effect on location compared to object change trials, this pattern of results suggests an age-related disadvantage that was specific to identifying location changes. Our findings thereby suggest dissociable mechanisms may have been involved in processing either scene type (object and location change), and an age-related inefficiency in those processes specific to the location trials.

Hippocampal Impairment

Our hypotheses rest upon the presumption that older adults exhibit degradation of the hippocampus (Persson et al., 2012), a structure shown to be important for both spatial processing and episodic memory. Our sample of healthy older adults should not have a dramatic level of hippocampal dysfunction. Therefore, we expect any differences in the quality of HC representations between YA and OA should be subtle. However, the gradual decline may slow down OA's HC function, leading to slower reaction times for HC-dependent processes. Consequently, our findings that age influenced reaction time, but not accuracy, imply such a pattern of early HC degradation in our older adult sample. Furthermore, our results showed greater within-group variability in OA response time, which consistent with findings that the age of onset of HC-related memory decline varies between individuals (Persson et al., 2012).

Although memory decline in old age has been extensively studied (Balota et al., 2000), there is no consensus about how age affects visuospatial perception. Therefore, our study attempted to extends the current literature investigating age-related differences in the ability to process visual scenes. Furthermore, since our task had little mnemonic demands, we dissociate any age-related deficits from spatial memory impairments that occur in healthy aging. In that vein, our findings point in the same direction as studies of amnesic patients with HC damage. Amnesia is characterized by severe memory loss, a deficit directly linked to the severity of damage to the HC (Scoville & Milner, 1957). The location and extent of amnesic lesions has also been attributed to specific perceptual deficits. Our results follow a similar pattern of perceptual deficits as found in amnesia. Like amnesic patients in Lee, Buckley et al.'s (2005) study, older adults in our study were worse at discriminating between scenes compared to healthy and younger controls, respectively. Further, like our older adults, amnesiac patients with damage to the HC showed less or no impairment in perception of objects. This parallel provides a compelling similarity between perceptual impairments related to aging and amnesia, which are both associated with hippocampal degradation (Persson et al., 2012; Scoville & Milner, 1957). Crucially, this deficit appears selective to processing spatial configurations, whereas perception of individual objects remains spared. Given that OA's accuracy was not compromised in our study, their deficit is subtle.

The general pattern of our results suggests a potential difference between the

ability to process a single object as opposed to the spatial relations between objects. Under the representational hierarchical model, objects and scenes are processed at different stages of the visual processing stream (Lee et al., 2012). Mental representations of complex scenes are achieved by combining disparate objects into coherent scene representations, integrating the spatial relations between elements. This model attributes the hippocampus to this role, as being responsible for creating complex spatial conjunctions of objects processed in posterior regions. If hippocampal function is impaired in older adults, as suggested by Persson et al.'s (2012) longitudinal findings, their ability to create scene representations would be compromised, whereas object perception may be spared. This was the case in our study: older adults were slower at responding to scenes that contained the same objects but in a different spatial configuration. Therefore, our pattern of findings fit with the representational hierarchical model, by implying that OA's presumed HC-dysfunction impairs perception of scenes more so than objects. This may be indicative of an impairment at combining individual objects into a coherent scene representation. Our study therefore extends the previous literature by demonstrating a pattern of HC-related perceptual deficits in non-amnesic OA similar to that observed in HC-damaged amnesic patients.

Allocentric Spatial Processing

The present study was designed to engage participants' use of disparate information to create mental representations of scenes. Location mismatches could not be identified by observing a single object in isolation. Rather, it was necessary to consider an object's position relative to other scene elements, then to compare the resulting association between images. Such allocentric processing, in which object locations are coded relative to one another, involves hippocampal activity, as demonstrated by Moffat and colleagues (2006). Critically, they showed that these regions known to support allocentric navigation are less activated in older adults, compared to younger adults. This decline in activity may be associated with impaired performance in tasks requiring allocentric processing, such as location change trials in our study.

In an allocentric task by Antonova and colleagues (2009), older adults relied more on proximal cues to navigate a virtual environment and were therefore impaired when combining multiple cues to create an allocentric spatial representation. In the present

study, it is possible that older adults used egocentric strategies, also relying more on proximal cues than younger adults did. Here, an allocentric conjunction of cues would enable scenes to be processed as a whole, in which their constituent spatial relations are available for comparison. Instead, older adults may have employed serial comparison of each object and the other scene elements near to it. Although this strategy may have worked for single items in the training tasks, it was likely inefficient when multiple scene elements were introduced in the main task. Should OA have employed a more time-consuming egocentric processing strategy, this would explain their slower responses on location trials. Crucially, the choice of strategy appears to have been irrelevant for object change trials. Altogether, a separate mechanism may be involved in processing objects, which is less sensitive to aging.

Our findings are also consistent with the aspects of spatial memory known to be affected in aging. Clark and colleagues (2017) showed that although older adults perform similarly to younger adults when remembering the location of a single item, they perform worse when the need to combine multiple spatial locations is introduced. Our study reveals a similar deficit in spatial relational processing, in which the conjunction of multiple object locations was impaired in older adults, whereas perception of objects was not affected. Specifically, we observed these deficits even though the to-be-compared stimuli were presented simultaneously. Our results therefore extend past findings in suggesting that older adults may be impaired in a spatial relational perception task that has no mnemonic demands.

Scenes and Memory

Our study also provides insight into how age affects associative processing. In location change trials, participants needed to consider the spatial relations between multiple scene elements to retrieve their respective locations. Older adults were slower on such trials, suggesting a decreased efficiency at encoding and manipulating spatial associations. Previous literature shows that age affects memory for associations more so than memory for single items. Our findings demonstrate a similar pattern even when information did not need to be stored into memory. Age-related decline in associative memory may therefore be related to impaired initial processing of associations. Although this deficit is typically manifested at retrieval, results of the present study hint that it may

be present at the time of perception. This interpretation agrees with the associative deficit hypothesis, which states that impaired associative processing ability underlies memory decline in old age (Naveh-Benjamin et al., 2003).

The present study also has implications regarding the nature of episodic memories. Although older adults were generally slower across scene types, this hindrance was greater when they compared the spatial relations between scene elements, rather than comparing object identities. It is plausible that while older adults view a visual scene, there is less useful information about its spatial configuration processed over time, in comparison to younger adults. Accurate scene construction might therefore be an effortful process and more susceptible to errors in older adults. In an everyday context, this could lead to less accurately encoded spatial representations of one's environment. Scenes are important for episodic memory, providing a spatial context to which event details can be bound (Robin & Olsen, 2019), thus promoting accurate and detailed recall of events (Robin et al., 2015). Given the intricate link between scenes and episodic memory, a connection can be made between the availability and quality of spatial representations and episodic memory ability. Older adults may not experience a benefit from memories involving a strong spatial component. Rather, they may be disadvantaged given their reduced access to spatial representations of their environment. This is consistent with Hassabis and Maguire's (2007) theory that episodic memory relies on scene construction, which enables the vivid recollection of past experiences. Overall, our study encourages future research into the intricate relation between episodic memory and scene perception.

Limitations

There are several limitations to bear in mind when interpreting our results. Firstly, although we had no explicit hypotheses about the viewpoint manipulation alone, we assumed that both off-centre (left and right) viewpoints would differ from the center viewpoint. Instead, preliminary analyses generally found that only the right viewpoint was different from the center. Given that the 3-dimensional virtual room was always presented on the right side of the screen, we suspect that participants' relative perspective towards the image interfered with the perspective within the image. If participants remained fixated at the center of the screen, rooms presented from a center perspective would actually appear to be from the left, given that the participant would be facing the

image from the left. Therefore, it might be that when the image was shown from a left perspective, the view aligned with what the participant saw anyway, resulting in a central perspective rather than left, as was intended. However, when the room was presented from the right perspective, additional effort may have been required in order to mentally rotate the image into a usable viewpoint. Further adaptations of this paradigm should carefully consider the viewpoint manipulation. We recommend that future research vary the visual field in which the virtual room is presented, in addition to the perspective contained within the image. This would allow researchers to identify whether participants' actual view of the image was sufficient to interact with and create a viewpoint manipulation.

Next, individuals vary in their memory ability as they age, and memory decline is associated with reduced hippocampal activation (Persson et al., 2012). There is no single age of onset at which the hippocampus begins to degrade; therefore without neuroimaging, we cannot confirm whether older adults in our sample exhibited hippocampal dysfunction. Although participants did complete a separate neuropsychological assessment for this purpose, those results are beyond the scope of the current analyses. It is therefore impossible to correlate participants' task performance with their ability in various cognitive domains. Such analyses may elucidate whether older participants in our study are also impaired in other domains known to be sensitive to HC dysfunction, for example: associative memory as assessed by the Face Name Associative Memory Exam (Rentz et al., 2011). Further, more general impairments in other cognitive abilities may be indicative of broader neurological damage beyond the HC, which may have provided a basis on which to exclude participants based on neurological health. For the present study, however, we relied on participants' self-reports in the pre-screening to ensure that they were in good neurological health. Nonetheless, our results are generally compatible with our assumptions and previous literature. Further research involving a more comprehensive neuropsychological assessment may be better suited to investigate HC-related impairment of visuospatial processing in old age.

Finally, our analyses indicate that performance on match trials generally showed the same patterns as in location change trials. Although we mainly consider differences between location and object change trials, it is still useful to discern why this may occur.

In our study, matches can be considered as target-absent trials in a visual search paradigm. Although participants may use specific mechanisms for identifying the presence of a target (object or location change) as previously discussed, matches could only be determined by ruling out the other possibilities. Therefore, those same mechanisms would need to be used on match trials. This explains why match trials showed similar patterns of performance as location trials, given that they overlapped in the processes participants used to resolve them.

Conclusions

In sum, the present study found age differences in the speed of processing for visuospatial relational perception, but not object perception. Our findings agree with studies of amnesic patients and are consistent with other aspects of memory and spatial cognition known to be impaired in older adults. We suspect that these findings are indicative of age-related hippocampal decline, given the structure's particular involvement in scene perception. To our knowledge, there have been few attempts to investigate visuospatial perception in healthy older adults outside of the mnemonic domain. Using a novel paradigm with little mnemonic demands, we present unique findings of age-related deficits in spatial relational perception. These may have important implications towards episodic memory ability in older adults. Overall, our study encourages future research into the complexity of episodic memory decline and its potential basis in spatial perception.

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Appendices

Appendix A

Informed Consent



Age-related differences in spatial relational processing

Undergraduate Researcher: Ms. Olivia Bizimungu

Primary Investigator: Dr. Danielle Douglas; Assistant Professor, Department of
Psychology

PARTICIPATION CONSENT

You are invited to participate in an online experiment that will improve our understanding of how the human brain supports perception and memory conducted by Ms. Bizimungu under the supervision of Dr. Danielle Douglas in the Department of Psychology at Mount Allison University. This study will assess how the visual attributes of stimuli affect how they are processed. The aim of this project is to better understand visual perception and visual memory.

In this study, you will be shown a series of images on a computer screen and asked to answer yes or no questions about those images by pressing buttons on a keyboard. You may also be asked to describe your experience of the task and answer some questions about yourself. You may choose to not answer any questions for any reason.

The study is estimated to take approximately 75 minutes. You will be compensated based on your time participating in the study. For 15 minutes of participation, for example, you would receive \$2.5 (CAD); for 30 minutes, you would receive \$5. Completing this study in the estimated 75 minutes, you would receive \$12.50 (CAD).

You are not obligated to participate in this study, and you are free to discontinue at any time. If you choose to end the experiment early, or if you change your mind after the

experiment is completed, you can return your submission and your data will not be used in the study. If you choose to withdraw, this will have no bearing on your remuneration. The researchers do not anticipate any risks or direct benefits to you or others related to the study. No personally identifying information will be collected at any point in this study. A unique identifier will be used to link your submissions, verify eligibility and process compensation via Prolific Academic.

Please note that this online study is facilitated by Pavlovia, a company that operates, and collects and stores data on servers in the UK. Therefore, Pavlovia is subject to the laws of its respective jurisdictions. Pavlovia is fully compliant with the General Data Protection Regulation (GDPR). For more information on Pavlovia's privacy policy, consult <https://pavlovia.org/docs/home/ethics>). If you choose to participate in the study, you understand that your responses to the questions will be stored and accessed in the UK.

The results of this research will be shared through conferences and in peer-reviewed journals. You may directly inquire about the outcome of the study with Dr. Douglas via her contact information, detailed below. In all cases, the reports will not include any information that might identify you or any other participant personally, including name, student number, Prolific Academic ID or demographic information.

If you have any questions about this study, please contact Dr. Danielle Douglas at ddouglas@mta.ca. This research has been reviewed and approved by the Mount Allison University Research Ethics Board. If you have any questions or concerns about this study, you may contact Dr. Lisa Dawn Hamilton, Chair of the Mount Allison University Research Ethics Board, by phone (506-364-2618) or by e-mail at reb@mta.ca.

By clicking YES, you are indicating that you fully understand the above information and agree to participate in this study.

- Yes, I agree to participate.
- No, exit the study.

Appendix B

Pre-screening questionnaire

Please answer the following questions truthfully

What is your age in years?

How many years of education have you completed since grade 1?

(For example, completing up to grade 5 = 5 years)

Which is your dominant hand?

- Left
- Right
- Both

What is your gender identity?

- Woman
- Man
- Non-binary
- My gender identity is not listed above
- Prefer not to say

What is your sex assigned at birth?

- Female
- Male

Intersex

Prefer not to say

At what age did you learn English?

Check all that apply to your eyesight

Glasses Bifocals Reading glasses Contacts None (normal vision without correction)

Are you color blind?

Yes No

Have you ever been diagnosed with any visual problems, such as cataracts, glaucoma, or macular degeneration?

Yes No

Have you ever been diagnosed with any hearing problems?

Yes No

Have you ever been diagnosed with any heart, circulation or respiratory problems? (E.g. high/low blood pressure)

Yes No

Have you ever had a seizure, stroke or multiple sclerosis?

Yes No

Have you ever had a head trauma?

Yes No

Did your head trauma result in loss of consciousness for more than a few seconds?

Yes No Not applicable

Have you ever been diagnosed with epilepsy?

Yes No

Have you ever been diagnosed with ADD, or ADHD?

Yes No

Have you ever been diagnosed with depression or anxiety?

Yes No

If you answered yes to the above question, are you currently depressed or anxious?

Yes No Not applicable

Have you ever been diagnosed with any other psychological or neurological condition?

Yes No

Do you feel you have memory problems greater than those of your peers?

Yes No

Please list any other health problems that you haven't mentioned so far

If you are taking medication for any of the conditions mentioned above, please list the medications you are currently taking

Anything else you wish to add or specify

Appendix C

Debriefing



Age-related differences in spatial relational processing

Ms. Olivia Bizimungu, Undergraduate Researcher

Dr. Danielle Douglas, Assistant Professor, Department of Psychology

PARTICIPATION DEBRIEFING

Thank you for participating in this experiment. In the current study, we wanted to see whether the way people process certain kinds of spatial relationships changes with age. Specifically, we examine whether the spatial relationship between the floorplan and 3D scene images is represented differently at different ages. We also asked you to complete a battery of neuropsychological tasks and fill out questionnaires that measure a variety of cognitive abilities, including your ability to visually imagine places and things, to remember associations, and process visuospatial information. These assessments will help us determine how representation of the spatial environment changes with age, and how these representations relate to other cognitive functions and underlying brain structures.

We would like to thank you again for participating. If you have any questions or concerns, please feel free to contact Dr. Douglas (ddouglas@mta.ca). This research has been reviewed and approved by the Mount Allison University Research Ethics Board. If you have any questions or concerns about this study, you may contact Dr. Lisa Dawn Hamilton, Chair of the Mount Allison University Research Ethics Board, by phone (506-364-2618) or by e-mail at reb@mta.ca.

Appendix D

Survey of Autobiographical Memory.

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Survey of Autobiographical Memory (SAM)

Please indicate the strength of your agreement with each of the following statements.

1 Strongly disagree 2 Disagree somewhat 3 Neither agree nor disagree 4 Agree somewhat 5 Agree strongly

Episodic (event)

- 1). Specific events are difficult for me to recall (R)
- 2). When I remember events, I have a hard time determining the order of details in the event (R)
- 3). When I remember events, in general I can recall objects that were in the environment
- 4). When I remember events, in general I can recall what I was wearing
- 5). I am highly confident in my ability to remember past events
- 6). When I remember events, I remember a lot of details
- 7). When I remember events, in general I can recall which day of the week it was
- 8). When I remember events, in general I can recall people, what they looked like, or what they were wearing

Semantic

- 1). I can learn and repeat facts easily, even if I don't remember where I learned them
- 2). After I have read a novel or newspaper, I forget the facts after a few days (R)
- 3). After I have met someone once, I easily remember his or her name
- 4). I can easily remember the names of famous people (sports figures, politicians, celebrities)
- 5). I have a hard time remembering information I have learned at school or work (R)
- 6). I am very good at remembering information about people that I know (e.g., the names of a co-worker's children, their personalities, places friends have visited etc.)

Spatial

- 1). In general, my ability to navigate is better than most of my family/friends
- 2). After I have visited an area, it is easy for me to find my way around the second time I visit

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- 3). I have a hard time judging the distance (e.g., in meters or kilometers) between familiar landmarks (R)
- 4). I get lost easily, even in familiar areas (R)
- 5). If my route to work or school was blocked, I could easily find the next fastest way to get there
- 6). I use specific landmarks for navigating.

Future

- 1). When I imagine an event in the future, the event generates vivid mental images that are specific in time and place
- 2). When I imagine an event in the future, I can picture the spatial layout
- 3). When I imagine an event in the future, I can picture people and what they look like
- 4). When I imagine an event in the future, I can imagine how I may feel
- 5). When I imagine an event in the future, I can picture images (e.g., people, objects, etc)
- 6). I have a difficult time imagining specific events in the future (R)

R = Reverse Coded Items

Appendix E

Verbalizer-Visualizer Questionnaire.

Please circle True or False on whether these statements describe you.

I enjoy doing work that requires the use of words.	True	False
I enjoy learning new words.	True	False
I can easily think of synonyms for words.	True	False
I read rather slowly.	True	False
I prefer to read instructions about how to do something rather than have someone show me.	True	False
I have better than average fluency in using words.	True	False
I spend little time attempting to increase my vocabulary.	True	False
I dislike word games like crossword puzzles.	True	False
I dislike looking words up in dictionaries.	True	False
I have a hard time remembering the words to songs.	True	False
I don't believe that anyone can think in terms of mental pictures.	True	False
I find illustrations or diagrams help me when I'm reading	True	False
I have a hard time making a "mental picture" of a place that I've only been to a few times.	True	False
I seldom use diagrams to explain things.	True	False
I like newspaper articles that have graphs.	True	False
I don't like maps or diagrams in books.	True	False
When I read books with maps in them, I refer to the maps a lot.	True	False
The old saying "A picture is worth a thousand words" is certainly true for me.	True	False
I have always disliked jigsaw puzzles.	True	False
I find maps helpful in finding my way around a new city.	True	False
My dreams are sometimes so vivid I feel as though I actually experience the scene	True	False
My powers of imagination are higher than average.	True	False
I seldom dream.	True	False
My dreams are extremely vivid.	True	False
My dreams are rather indistinct and hazy.	True	False
I seldom fantasize.	True	False
I enjoy daydreaming.	True	False
I often dream about things I'd like to be.	True	False
I can hardly ever remember my dreams.	True	False
I seldom daydream.	True	False

Appendix F

Vividness of Mental Imagery Questionnaire.

Vividness of Mental Imagery Questionnaire (VVIQ)

Instructions

Visual imagery refers to the ability to visualise, that is, the ability to form mental pictures, or to “see in the mind’s eye”. The aim of this test is to determine the vividness of your visual imagery. The items of the test will possibly bring certain images to your mind. You are asked to rate the vividness of each image by reference to the 5-point scale given below. For example, if your image is “vague and dim” then give it a rating of 4. After each item write the appropriate number in the box provided. Please familiarise yourself with the different categories on the rating scale and refer to the rating scale when judging the vividness of each image. Try to do each item separately, independent of how you may have done other items.

Scale

- 1..... Perfectly clear and as vivid as normal vision
- 2..... Clear and reasonably vivid
- 3..... Moderately clear and vivid
- 4..... Vague and Dim
- 5..... No image at all, you only “know” you are thinking of a object

Items

Think of a friend or relative whom you frequently see (but who is not with you at present) and consider carefully the picture that comes before your mind’s eye.

1. The exact contour of the face, head, shoulders, body
2. Characteristic poses or head, attitudes of body, etc.
3. The precise carriage, length of step etc. in walking
4. The different colours worn in some familiar clothes

Visualise the rising sun. Consider carefully the picture that before your minds eye.

5. The sun is rising above the horizon into a hazy sky
6. The sky clears and surrounds the sun with blueness
7. Clouds. A storm blows up, with flashes of lightning
8. A rainbow appears

Think of the front of a shop which you often visit. Consider the image before your mind’s eye.

9. The overall appearance of the shop from the other side of the road
10. A window display including colours, shapes and details of the individual items on sale
11. You are near the entrance. The colour and shape of the door

12. You enter the shop and go to the counter. The counter assistant serves you. Money changes hands.

Finally think of a country scene which involves trees, mountains and a lake. Consider the picture that comes before your mind's eye.

13. The contours of the landscape

14. The colour and shape of the trees

15. The colour and shape of the lake

16. A strong winds blows on the trees and on the lake causing waves.

Thank you for taking part.

Appendix G

Memory Functioning Questionnaire.

This is a subjective questionnaire about your cognitive function. There are no right or wrong answers. Select a number between 1 and 7 that best reflects your judgement about your memory. Please answer all of the questions.

Overall Memory	Poor		Good			Excellent	
How would you rate your memory in terms of the kinds of problems that you have?	1	2	3	4	5	6	7

How is your memory compared to the way it was	Much Worse		Same			Much Better	
One year ago?	1	2	3	4	5	6	7
Five years ago?	1	2	3	4	5	6	7
Ten years ago?	1	2	3	4	5	6	7
Twenty years ago?	1	2	3	4	5	6	7
When you were eighteen?	1	2	3	4	5	6	7

How often do these present a problem for you?	Always		Sometimes			Never	
Names	1	2	3	4	5	6	7
Faces	1	2	3	4	5	6	7
Appointments	1	2	3	4	5	6	7
Where you put things (e.g., keys, t.v. remove, etc.)	1	2	3	4	5	6	7
Performing household chores	1	2	3	4	5	6	7
Directions to places	1	2	3	4	5	6	7
Phone numbers you've just checked	1	2	3	4	5	6	7
Phone numbers you've used recently	1	2	3	4	5	6	7
Things people tell you	1	2	3	4	5	6	7
Keeping up correspondence	1	2	3	4	5	6	7
Personal dates (e.g., birthdays)	1	2	3	4	5	6	7

How often do these present a problem for you?	Always	Sometimes	Never
Words	1 2	3 4 5	6 7

How often do these present a problem for you?	Always	Sometimes	Never
Going to the store and forgetting what to buy	1 2	3 4 5	6 7
Taking a test	1 2	3 4 5	6 7
Beginning to do something and forgetting what you were doing	1 2	3 4 5	6 7
Losing the thread of thought in a conversation	1 2	3 4 5	6 7
Losing the thread of thought in public speaking	1 2	3 4 5	6 7
Knowing whether you've already told someone something	1 2	3 4 5	6 7

As you are reading a novel, how often do you have trouble remembering what you have read	Always	Sometimes	Never
In the opening chapters, once you have finished the book:	1 2	3 4 5	6 7
Three or four chapters	1 2	3 4 5	6 7
The chapter before the one you are currently reading	1 2	3 4 5	6 7
The paragraph just before the one you are currently reading:	1 2	3 4 5	6 7
The sentence before the one you are currently reading	1 2	3 4 5	6 7

When you are reading a newspaper or magazine article, how often do you have trouble remembering what you have read?	Always	Sometimes	Never
In the opening paragraphs, once you have finished the article	1 2	3 4 5	6 7
Three or four paragraphs before the one you are currently reading	1 2	3 4 5	6 7
The paragraph before the one you are currently reading	1 2	3 4 5	6 7
Three or four sentences before the one you are currently reading	1 2	3 4 5	6 7
The sentence before the one you are currently reading	1 2	3 4 5	6 7

How well do you remember things which occurred...	Very Bad	Fair	Very Good
Last month	1 2	3 4 5	6 7
Between six months and one year ago	1 2	3 4 5	6 7
Between one and five years ago	1 2	3 4 5	6 7
Between six and ten years ago	1 2	3 4 5	6 7

When you actually forget in these situations, how serious of problem do you consider the memory failure to be?	Very Serious	Somewhat Serious	Not Serious
Names	1 2	3 4 5	6 7
Faces	1 2	3 4 5	6 7
Appointments	1 2	3 4 5	6 7

When you actually forget in these situations, how serious of problem do you consider the memory failure to be?	Very Serious	Somewhat Serious	Not Serious
Where you put things (e.g., keys)	1 2	3 4 5	6 7
Performing household chores	1 2	3 4 5	6 7
Directions to places	1 2	3 4 5	6 7
Phone numbers you've just checked	1 2	3 4 5	6 7
Phone numbers used frequently	1 2	3 4 5	6 7
Things people tell you	1 2	3 4 5	6 7
Keeping up correspondence	1 2	3 4 5	6 7
Personal dates (e.g., birthdays)	1 2	3 4 5	6 7
Words	1 2	3 4 5	6 7
Going to the store and forgetting what you wanted to buy	1 2	3 4 5	6 7
Taking a test	1 2	3 4 5	6 7
Beginning to do something and forgetting what you were doing	1 2	3 4 5	6 7
Losing the thread of thought in conversation	1 2	3 4 5	6 7
Losing the thread of thought in public speaking	1 2	3 4 5	6 7
Knowing whether you've already told someone something	1 2	3 4 5	6 7

How often do you use these techniques to remind yourself about things?	Always	Sometimes	Never
Keep an appointment	1 2	3 4 5	6 7
Write yourself reminder notes	1 2	3 4 5	6 7
Make lists of things to do	1 2	3 4 5	6 7
Make grocery lists	1 2	3 4 5	6 7

How often do you use these techniques to remind yourself about things?	Always	Sometimes	Never
Plan your daily schedule in advance	1 2	3 4 5	6 7
Mental repetition	1 2	3 4 5	6 7
Association with other things	1 2	3 4 5	6 7
Keep things you need to do in a prominent place where you will notice them	1 2	3 4 5	6 7