

**Age-Related Differences in Spatial Processing**

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## Abstract

Associative memory, especially episodic memory, declines in old age—an effect ascribed to age-related decline in the hippocampus. The hippocampus also supports some form of spatial processing, and some have suggested that the decline of spatial processing as early as perception could underly episodic memory deficits. However, to date, no one has investigated spatial processing in older adulthood without the confound of long-term memory demands. I therefore examined age-related differences in spatial perception by having 29 participants complete a novel spatial task that minimized memory demands. The sample comprised 15 younger adults ( $M_{age} = 25$ ;  $SD = 5.75$ ) and 14 older adults ( $M_{age} = 64$ ;  $SD = 3.77$ ). Participants compared screenshots of 3D virtual rooms to simultaneously presented 2D room layouts and indicated whether the rooms were identical or not. My results indicated no age-related difference in accuracy scores on either location or object-based trials. However, older adults spent significantly longer on location-based trials than younger adults did. These results suggest that healthy older adults exhibit subtle age-related deficits in spatial processing, even at perception. My findings support theories proposing that an age-related deficit in spatial processing may cause episodic memory problems in older adults.

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## **Age-Related Differences in Spatial Processing**

Memory deficits in older adults have been explored extensively in the literature; however, little is known about how or why these occur (Lee et al., 2012). Compared to other memory types, older adults experience the most dramatic deficits in those that require forming associations (Gutchess & Park, 2009; Naveh-Benjamin, 2000). Among these, episodic memory, our memory for past events and experiences, declines the most dramatically with age (Baddeley et al., 2020). The hippocampus, a brain region in the medial temporal lobe (MTL), plays an important role in episodic memory and associative processing, and older adults experience age-related deficits in both (Naveh-Benjamin, 2000; Suzuki, 2005).

The hippocampus has also been associated with spatial navigation deficits in older adults, another process that requires forming associations between the elements of our environment (Moffat et al., 2009). When navigating our environment, we rely on multiple cues that help us determine our location in space, which places a demand on the learned associations acquired in memory. This has been shown in multiple studies demonstrating the activation of the hippocampus during virtual environment navigation tasks (Moffat, 2006; Moffat, 2009). As we age, our ability to accurately navigate our environment declines, as does hippocampal activity during these tasks (Moffat, 2006; Moffat, 2009).

The idea that deficits in spatial processing cause memory deficits in older adults has been widely unexplored. However, findings suggest that older adults experience the most dramatic deficits on memory tasks requiring associative processing (Klencklen et al., 2012; Moffat, 2006). Furthermore, these processing deficits are both associated with activity in the hippocampus. This has been shown in hippocampus damaged patients who have difficulty discriminating between two similar scenes (Lee et al., 2005; McCormick

et al., 2017). Therefore, this may suggest that the hippocampus plays an important role in scene perception and that this ability is diminished in older adults. To date, no studies have examined age related differences in spatial processing using a task that minimizes mnemonic processing. The aim of the current study is to therefore examine whether a spatial processing deficit exists in older adults, independent of memory deficits.

### **Older Adults and Memory**

Memory types and their processing demands vary; therefore, it is important to differentiate between which aspects of memory are affected in older adults and which are not. Memory types that do not involve forming and maintaining associations seem to be the least affected with age (Giambra et al., 1995; Ihle et al., 2012). In fact, semantic memory, our declarative memory for facts and information, has been shown to improve with age (Giambra et al., 1995). Though semantic memory seems to be relatively preserved as we age, episodic memory declines rapidly along a linear trend. In contrast to other forms of memory, episodic memory relies heavily on learned and remembered associations, which individuals seem to have the most trouble with as they age (Salthouse, 1991, Tulving & Markowitsch, 1998).

The finding that episodic memory decreases rapidly compared to other memory types led Naveh-Benjamin (2000) to explore why this was. They found that healthy older adults were significantly impaired at creating associations between semantically unrelated word pairs compared to semantically related word pairs in contrast to healthy younger adults. Importantly, the semantically unrelated word pairs required forming new associations in memory, whereas the semantically related word pairs relied on previously made associations (Naveh-Benjamin, 2000). This finding indicates that older adults have significant trouble encoding new associations in memory, which may partially explain

why they exhibit episodic memory deficits: creating an episodic memory relies on forming associations between the elements in our environment (Naveh-Benjamin, 2000). Moreover, these findings show that associative processing is clearly impoverished as we age, and these processes seem to play an important role in the type of memory deficits observed (Naveh-Benjamin, 2000). These findings led Naveh-Benjamin (2000) to propose the associative deficit hypothesis. The associative deficit hypothesis proposes that age related memory deficits result from older adults decreased ability to bind unrelated aspects of an episode into a cohesive whole (Naveh-Benjamin, 2000). The hypothesis of Naveh-Benjamin (2000) has gained considerable support from studies that have replicated and extended their findings with different stimuli, such as those using name-face pairs and image pairs (Naveh-Benjamin et al., 2003; Overman & Becker, 2009).

The idea that associative processes play an important role in memory has extended to include the importance of scenes in episodic memory. When we encode and retrieve information about events, a spatial context is always present. This has led to the proposition that spatial context acts as a scaffold for the encoding and retrieval of episodic memories (Robin et al., 2015). This idea was supported by findings from Robin and Olsen (2019), who had participants study object pairs, face-object pairs, and scene-object pairs. At recall, participants remembered objects that were associated directly with a scene better than those associated with a face or an object. Moreover, they recalled indirect associations between objects that were never presented together but were paired with the same scene. Robin and Olsen (2019) tracked participant eye-movement during encoding and retrieval and found a greater number of fixations to faces compared to scenes. Thus, scenes were still associated with better memory even though participants

fixated on faces more. These findings support the idea that forming associations with scenes may facilitate episodic memory, given that items were better recalled when associated with a scene.

Episodic memory and associative processes are linked by a common neural structure, the hippocampus of the MTL. Attention was first brought to the MTL after Patient H.M. was unable to form new memories following bilateral lesions to the hippocampus (Scoville & Milner, 1957). Ever since this discovery, many human and non-human animal studies have found the hippocampus to be essential for declarative memory processes, especially those involving episodic memory (O'Shea et al., 2016; Vargha-Khadem et al, 1997). In a longitudinal study done by Vargha-Khadem et al. (1997), individuals with bilateral hippocampal pathology stemming early in life had significant difficulty remembering daily events and experiences. However, their semantic knowledge remained intact with age, and patients attained average to low average scores in mainstream schooling. Since the patients had pathology specific to the hippocampus, these findings indicate that episodic memory may be largely dependent on this area of the brain. Conversely, since they had little issue with their semantic knowledge, this suggests that semantic memory may depend less on the hippocampus (Vargha-Khadem et al, 1997). However, because it is difficult to assess the extent of brain damage in such patients, this could mean that deficits found were due to damage in other closely related brain areas (Pohlack et al., 2014).

Eldridge et al. (2000) controlled for the limitations of Vargha-Khadem et al. (1997) by examining hippocampal activity during the retrieval of episodic memories in healthy, young adults. They asked participants to memorize a list of words for a memory test that they would complete later (Eldridge et al., 2000). Twenty minutes later,

participants were presented a list including words they did and did not study. For each word on the list, they were asked to identify if they had studied it or not and whether their memory for that word was episodic (remember) or familiar (know). While doing this, they underwent event-related functional Magnetic Resonance Imaging (fMRI). When participants exhibited recollection of the learning episode during retrieval, they exhibited increased activity in the hippocampus, whereas hippocampal activity decreased when this conscious recollection was absent, even if the word was remembered based on familiarity. This finding shows that hippocampal activation increased during the recall of episodic material (Eldridge et al., 2000). Moreover, this suggests that the hippocampus is involved in associative processing since increased activity was only shown when individuals made conscious associations between the elements of a past learning episode (Eldridge et al., 2000).

Suzuki (2005) was able to demonstrate these associative processing deficits in monkeys by training them to complete a location-scene association task. Monkeys were trained to learn the association between visual scenes and the location of target items within them. Each day, monkeys were asked to point out the correct reward target item within a scene. If they did so correctly, they were rewarded. Following the study, the researchers found that 61% of monkeys isolated hippocampal cells were active during associative learning, indicating that the hippocampus is involved in these processes (Suzuki, 2005). Moreover, they found that 28% of these hippocampal cells exhibited changes in neural activity over the course of learning (Suzuki, 2005). These findings show that beyond episodic memory, the hippocampus is involved in forming learned associations between the elements of a complex scene (Suzuki, 2005).

Changes in hippocampal structure may be important in understanding the neural underpinnings of the cognitive aging process (O'Shea et al., 2016). Age-related decline in hippocampal volume has been associated with the onset of dementia and mild cognitive impairment (O'Shea et al., 2016; Schuff et al., 1999). However, hippocampal volume decline in healthy older adults has been relatively understudied; therefore, is poorly understood. Likewise, there have been controversial findings concerning hippocampal volume decrease in healthy older adults. Some studies support the notion that a decrease in hippocampal volume contributes to poorer episodic memory, while others have found no significant association between the two (Persson et al., 2012; Van Petten, 2004; Ystad et al., 2009). To resolve these controversies, O'Shea et al. (2016) measured healthy older adults' performance on a wide variety of cognitive tasks and used magnetic resonance imaging to measure their respective hippocampal volume. They found that hippocampal volume was able to predict older adults' cognitive performance, and that this was most evident for tasks that required episodic memory, processing speed, and working memory (O'Shea et al., 2016). Though the mechanisms underlying hippocampal volume decline in older adults is uncertain, this study suggests that age-related structural differences in the hippocampus affect episodic memory (O'Shea et al., 2016).

In conclusion, episodic memory is by far the most affected in older adults. In contrast to other memory types, such as semantic, procedural, and short-term memory, episodic memory relies on forming associations. Moreover, scenes have been shown to facilitate episodic memory, suggesting that spatial context acts as a scaffold for the encoding and retrieving of episodic memories. The hippocampus has been shown to be

involved in both episodic memory and associative processes, making it of particular interest in the study of why these deficits occur with aging.

### **Memory and Spatial Processing**

Navigating our environment relies on our ability to process the spatial location of landmarks, maps, and road signs. This process is dynamic and relies on forming representations of our environment relative to our own position in space (Ladyka-Wojik & Barense, 2021). Ever since the discovery that hippocampal “place cells” fire when rats enter specific areas in space, the hippocampus has been greatly studied for its role in spatial navigation (Tolman, 1948). Literature following this finding has proposed that the hippocampus acts as a “cognitive map” that constantly maintains representations of our spatial environment (O’Keefe & Nadel, 1978). Two important processes implicated in spatial navigation are egocentric and allocentric spatial memory. Egocentric spatial memory involves the encoding and retrieval of spatial information dependent on one’s own position in the world (Ladyka-Wojik & Barense, 2021). Conversely, allocentric spatial memory involves the encoding and retrieval of spatial information independent of one’s own position in the world, therefore, individuals code the aspects of their environment in relation to one another (Ladyka-Wojik & Barense, 2021).

While recent literature has brought attention to the neural underpinnings of allocentric and egocentric spatial representations, little is known regarding how these are encoded and stored in memory (Ekstrom et al., 2014; Ladyka-Wojik & Barense, 2021). The hippocampus has been suggested to hold scene representations for allocentric spatial information due to its important role in spatial navigation and episodic memory (Brunec et al., 2019; Fidalgo & Martin, 2016). Support for this has been demonstrated by Moffat (2009), who examined brain activity using fMRI in older and younger adults as they

completed virtual environment tasks. They found that older adults relied less on allocentric-based strategies and had attenuated hippocampal activity as they navigated a virtual environment. This contrasted with younger adults, who showed greater hippocampal activity and reliance on allocentric-based strategies during these tasks (Moffat, 2009). Research has also suggested that as we age, there becomes a greater tendency to rely on egocentric spatial memory during spatial navigation, even though allocentric-based strategies are preferred during these tasks (Ladyka-Wojcik & Barense, 2020; Moffat, 2009; Colombo et al., 2017). These findings support the proposition that brain structures involved in episodic memory may hold representations for spatial information as well, suggesting that the hippocampus may be involved in spatial processes beyond those prescribed to long-term memory.

Spatial navigation has been shown to have an age-related vulnerability in humans and non-human animals in real-world and virtual navigation tasks (Moffat et al., 2001; Morris et al., 1982). One of the most used behavioural tasks to assess spatial navigation deficits in older rats is the Morris water task, as non-human animal studies suggest it depends on hippocampal formation (Morris et al., 1982). This task involves having older rats locate a hidden platform, and findings indicate that older rats spend longer trying to find the platform and require more trials before successfully reaching the designated platform (Morris et al., 1982). Humans have also had their spatial navigation skills assessed using a modified version of the Morris Water Task, where they repeatedly placed and removed a pole from an enclosure surrounded by visual cues (Newman & Kaszniak, 2000). Over time, older adults showed greater error when placing the pole, suggesting they have deficits in place learning (Newman & Kaszniak, 2000).

Older adults also report experiencing trouble navigating their environment and report avoiding unfamiliar places and routes (Burns, 1999; Moffat, 2009). Moreover, age related decline in spatial navigation has been found thoroughly in humans using self-report surveys and direct assessments of navigational skills during virtual environment tasks (Moffat, 2009). Virtual environment tasks require the individual to navigate a virtual environment, sometimes while undergoing neuroimaging. One study demonstrated that the hippocampus, parahippocampal gyrus, medial parietal lobe and retrosplenial cortex were significantly activated in both younger and older adults when navigating a virtual environment (Moffat, 2006). All these areas have previously been related to allocentric spatial memory, indicating that these brain structures may play an important role in their representations. These areas were significantly attenuated in older adults compared to younger adults, which might suggest older adults rely on allocentric spatial representations less than younger adults during environmental navigation (Ekestrom et al., 2014; Moffat, 2006).

In conclusion, these findings support the idea that the hippocampus is involved in spatial navigation and is important for allocentric spatial memory. Episodic memory and spatial navigation both depend on the hippocampus, and both require forming and maintaining associations. Thus, these findings further suggest that older adults exhibit spatial processing deficits beyond those of long-term memory.

### **The Hippocampus and Spatial Perception**

The traditional account of MTL function proposes that it acts as a unitary declarative memory system: a system whose structures subserve long-term memory formation. Later models take on an informational account of MTL function, where the focus shifted to what kind of information each structure processed and how this was

important to the type of memory being examined. Informational accounts of MTL function hold the viewpoint that the hippocampus binds together relational items and contexts, though these models are purely mnemonic.

More recent accounts of MTL function argue that it engages in more than just mnemonic processing (Maguire & Mullally, 2013). Theoretical models such as the Scene Construction Theory or the Representational Hierarchical Model take on a novel view of the MTL, where the hippocampus is viewed as being essential in forming scene representations. The Representational Hierarchical model takes on a perceptual account of the MTL (Saksida & Bussey, 2010). This model proposes that the perirhinal cortex and parahippocampal cortex act as extensions off the ventral visual stream and the dorsal visual stream, respectively (Saksida & Bussey, 2010). The ventral visual stream carries visual identification information from the occipital lobe to the temporal lobe (Saksida & Bussey, 2010). Conversely, the dorsal visual stream carries spatial location information from the occipital lobe to the parietal lobe (Saksida & Bussey, 2010). These streams are theorized to carry informational inputs to the perirhinal cortex and parahippocampal cortex, which are near the entorhinal cortex and hippocampus (Saksida & Bussey, 2010). Given that the perirhinal cortex has been shown to process object information and the parahippocampal cortex has been shown to process spatial information, the hippocampus is in the perfect place to receive and integrate these representations into a perceptual whole. This model proposes that the hippocampus plays a vital role in scene representation, including scene perception.

The nature of the hippocampus has been widely argued, with many positing that it engages in either mnemonic, perceptual, or constructive information processing (Maguire & Mullally, 2013). While past literature has been dedicated to supporting a mnemonic

account, recent findings suggest that perceptual or constructive views may be more plausible since the hippocampus is evidenced to be involved in more than just memory (McCormick et al., 2017). The current literature review argues towards a representational account of MTL function based on evidence suggesting the hippocampus plays a role in spatial perception and the perirhinal cortex in object perception (Barens et al., 2012; Lee et al., 2005).

If the hippocampus is involved in scene processing, individuals with damage to the hippocampus should have trouble discriminating between two very similar scenes. This is because making such a discrimination would place a demand on internal scene modelling processes, thus making it difficult to differentiate between the two scenes (Lee et al., 2005). Findings show that scene discrimination is impaired in individuals with hippocampal damage when mnemonic confounds are minimized (Lee et al., 2005). Lee et al. (2005) had participants with selective hippocampal or greater MTL damage discriminate between similar faces, objects, and scenes. They found that amnesic patients with selective hippocampal damage had significant difficulty discriminating between scenes compared to objects and faces, whereas individuals with greater MTL damage extending to the perirhinal cortex were poorer at discriminating between both scenes and objects. These findings suggest that the perirhinal cortex may process object and item information, whereas the hippocampus may process scene information. These findings challenge the mnemonic view of the hippocampus, as they suggest it plays a role in scene perception.

In a later study, Lee et al. (2005) had patients with hippocampal and extensive MTL damage complete an oddity-judgment task. This involved having participants pick the odd stimulus out from a visual array of scenes. In contrast to their first study,

participants made discriminations between scenes or faces that differed on a single feature or by a slightly different viewpoint. They found that both groups of patients were impaired when the scenes differed by viewpoint but not a single feature, which further supports the possibility that the hippocampus is involved in scene perception. However, given that these patients already had episodic memory deficits, it could be possible that issues with scene discrimination resulted from holding both scenes constant in memory simultaneously (McCormick et al., 2017).

This discrepancy was controlled for by McCormick et al. (2017), who had participants with bilateral hippocampal lesions identify whether there were semantic (e.g., dog with butterflies for ears) or constructive (e.g., endless staircase) violations within the images they were presented. Therefore, making the image semantically or constructively ‘possible’ or ‘impossible’. In contrast to Lee et al. (2005), the possibility that patients had to hold both images present in memory simultaneously was controlled for by presenting them with one image at a time. They found that patients with hippocampal damage had difficulty differentiating between constructively impossible and possible scenes compared to semantically impossible and possible scenes. This finding suggests that the hippocampus plays a role in scene construction, given that mnemonic and perceptual demands were controlled for in the semantic condition and scenes were each presented one at a time. In support of this finding, Douglas et al., (2016) found greater hippocampal fMRI activity when perceiving impossible scenes over possible scenes.

While these findings evidence that the hippocampus plays a role in scene construction, it should be noted that scene construction and perception are intrinsically linked; we internally model the scene we are currently perceiving in the world around us (Mullally et al., 2012). The scene construction theory and the representational

hierarchical model both posit that the hippocampus plays a fundamental role in scene representation, thus these findings can be implicated in both models. Most importantly, these findings demonstrate that the hippocampus is involved in more than just mnemonic processing and plays a vital role in scene processing.

The perirhinal cortex has also been implicated in the visual perception of object and item stimuli. Perirhinal cortex lesions have been shown to impair performance on visual discrimination tasks. Lee et al. (2005) found that participants with greater MTL damage had difficulty differentiating between scenes and faces that could be discriminated by a simple visual feature. Importantly, the patients had little difficulty discriminating between familiar objects but significant difficulty differentiating between novel objects (Lee et al., 2005). Barense et al. (2012) further demonstrated that participants with MTL damage including the perirhinal cortex were significantly impaired when discriminating between objects with high feature ambiguity compared to participants that had MTL damage excluding the perirhinal cortex. Moreover, this was demonstrated using fMRI to evidence the recruitment of the perirhinal cortex during perceptual discrimination tasks. Altogether, these findings support that the perirhinal cortex plays an important role in complex object perception but not spatial perception. Furthermore, they support the Representational Hierarchical Model by demonstrating that the information processed by the perirhinal cortex is optimal for the hippocampus to integrate into a perceptual whole.

Scene perception deficits in amnesic patients with hippocampal damage during scene discrimination and scene oddity judgement tasks evidence the role of the hippocampus in perceptual processing. Moreover, evidence that lesions to the PRC evoke

visual discrimination deficits acts as support for the representational hierarchical model. These findings support the notion that the hippocampus plays an important role in spatial perception: it is not only in the perfect position to integrate spatial and object information from the perirhinal cortex and parahippocampal cortex but is also evidenced to play a specific role in scene perception. These findings also show that the perirhinal cortex does not function in scene perception. Given that the perirhinal cortex is not affected in age, processes that require discriminating between objects would not be expected to be affected in older adults.

### **Current study**

As we age, we experience dramatic deficits in episodic memory and spatial navigation. These deficits can be tied back to a common neural structure, the hippocampus. It has been suggested that the hippocampus holds underlying representations for stimuli involved in spatial perception (Douglas et al., 2016; Lee et al., 2005; McCormick et al., 2017). Moreover, scenes can facilitate associative memory processes and the hippocampus is activated during scene discrimination tasks (Douglas et al., 2016; Lee et al., 2005; McCormick et al., 2017; Robin & Olsen, 2019). Therefore, the memory and navigational problems that arise in older adults may be due to impoverished spatial representations, which are in turn caused by age-related decline in hippocampal integrity (Douglas et al., 2016; Lee et al., 2005; Robin & Olsen 2019).

Whether memory deficits arise from complex spatial processing deficits is largely unexplored. Therefore, the current study aimed to examine age-related differences in spatial perception. We were curious as to whether older adults and younger adults differed when processing object and location information during a task that places few demands on mnemonic processing. We employed a research design where participants

were required to differentiate between images of a floorplan and a room and identify whether they matched or did not match. Images differed in terms of the object presented, the location of the object presented or did not differ at all. Participant's reaction time and accuracy were recorded. Based on previous research suggesting that the hippocampus is associated with spatial deficits as we age, we proposed that older adults would have significantly greater reaction time than younger adults when object locations differed. Moreover, that older adults would be significantly less accurate than younger adults when object locations differed. To support these predictions, we expected a greater performance difference between age groups when object locations differed than when their identity differed. Based on findings indicating that the hippocampus is not involved in complex object representations, we also expected there to be no difference between younger and older adult accuracy or reaction time on object trials.

## **Method**

### **Participants**

Participants were recruited through word of mouth and Prolific academic for the current study. Fifteen younger adults aged 18-35 ( $M = 25$ ;  $SD = 5.75$ ) and 14 older adults aged 60-85 ( $M = 64$ ;  $SD = 3.77$ ) residing in Canada were eligible and recruited for this study. Participants were screened prior to assure that they were neurologically healthy and had corrected-to-normal vision. After completion, participants were compensated \$2.50 for every 15 minutes that it took them to complete the main study.

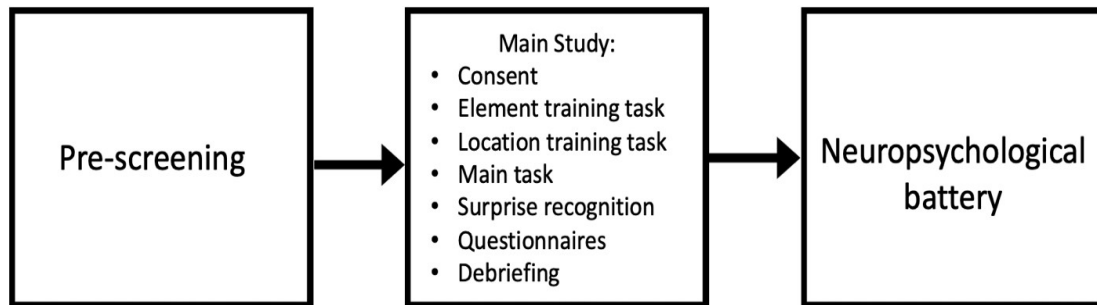
### **Materials**

Participants completed the study online using their own software device; thus computer, screen and operating system differed across participants for this study. Differences in monitor size and screen resolution were controlled for by having

participants complete a calibration task at the beginning of the study, ensuring that their display areas were scaled to 25.4 cm wide and 16.93 cm high. The current study was programmed using Version 6.1.0 of JSPsych (de Leeuw, 2015) and was administered to participants online through Pavlovia (<https://pavlovia.org>). Floor plans were created using Adobe Photoshop (version 2020, 21.0; Adobe Systems, San Jose, California) and 3D rooms were created using The Sims 4 (version 1.56.52.1020; Electronic Arts, Redwood City, California).

### **Overall Procedure**

An overview of the overall procedure is presented in Figure 1. Participants were first told the nature of the study and then provided informed consent. Participants were screened for eligibility using a pre-screening questionnaire that included demographic and health-related questions. Eligible participants were then invited to take part in the main study. Participants were randomly assigned to one of eight counterbalanced conditions. Conditions were counterbalanced by block order, on-screen stimulus presentation and the keys used to respond to the task. Participants completed the element training task, the location training task, the main task, the surprise recognition task and follow up questionnaires. On average, it took participants approximately 75 minutes to complete the main study. Following completion, participants were invited to complete the neuropsychological battery on another day.

**Figure 1***Overall Procedure.***Stimuli**

Images of floor plans and screenshots of 3D virtual rooms were used as stimuli for both the main and training tasks. Screenshot images were 3D room layouts, whereas floor plan images were line-drawn 2D room layouts which could be viewed from a bird's eye view. Each floorplan and screenshot image contained one or more of four scene elements: a counter, staircase, window, or door. The objects presented in the screenshot images differed in colour and pattern, with a total of 24 different variations across scenes.

***Element training***

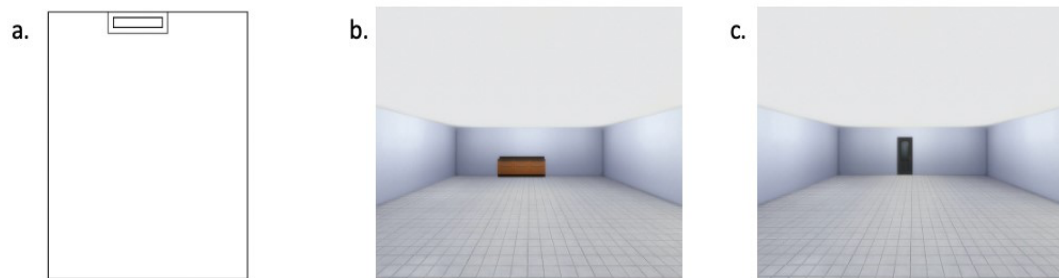
**Element training stimuli.** There was a total of 96 trials, which included 24 unique trials for each of the four scene elements. In half of the element trials, the element in the floorplan matched the element in the screenshot ("matched"; see Figure 2.b). In the other half of the element trials, the element in the floorplan differed from the element in the screenshot ("mismatched"; see Figure 2.c).

**Procedure.** Participants were shown example images of the four possible scene elements in both screenshot and floorplan images. They were shown images of scenes and asked, "Does the floorplan match the room?" to which they responded, 'yes' or

‘no’ using the ‘f’ and ‘j’ keys on their keyboard. Trials ended immediately after a response was given or after 5,500 ms if a participant took too long to respond. Participants were given text feedback (“Correct” or “Incorrect”) for 500 ms following each response. Following trials had an inter-stimulus interval of 1,000 ms.

## Figure 2

*Element Training Task Stimuli.*



Note. a. is an object match for b. and a. is an object mismatch for c.

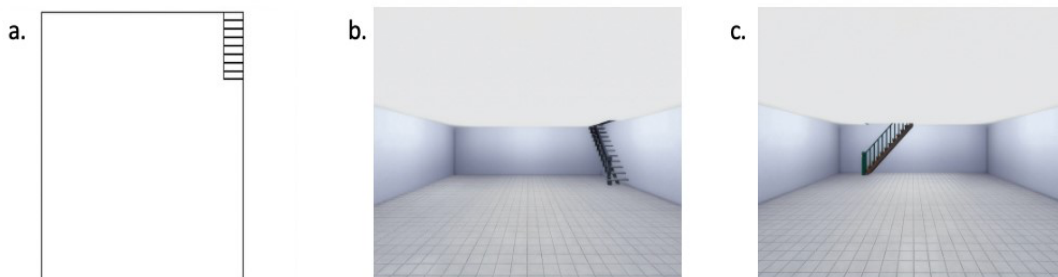
## *Location training*

**Location training stimuli.** The scene elements in the location trial only differed between floor plan and room images in location and not object identity. Such that, the type of element presented in a floorplan image never differed from that of which was presented in a screenshot image. If the location of a scene element did not differ in both floorplan and screenshot images, it was counted as a location “match” (Figure 3.b). Conversely, if a scene element’s location in a floorplan image did differ from its location in a screenshot image, it was characterized as a location “mismatch” (Figure 3.c). There was a total of 96 location trials, which included 24 unique trials for each of the four scene elements. Half of the trials contained location mismatches, whereas the other half contained location matches.

**Procedure.** Participants were first shown example images for each of the unique location trial “matches” or “mismatches”. After they were familiarized with these representations, they were shown images of scenes and asked, “Does the floorplan match the room?” to which they responded, ‘yes’ or ‘no’ by pressing the ‘f’ and ‘j’ keys on their keyboard. Trials ended immediately after a response was given or after 5,500 ms if a participant took too long to respond. Participants were given text feedback (“Correct” or “Incorrect”) for 500 ms following their responses. This was followed by consecutive inter-stimulus intervals of 1,000 ms.

### Figure 3

*Location Training Task Stimuli.*



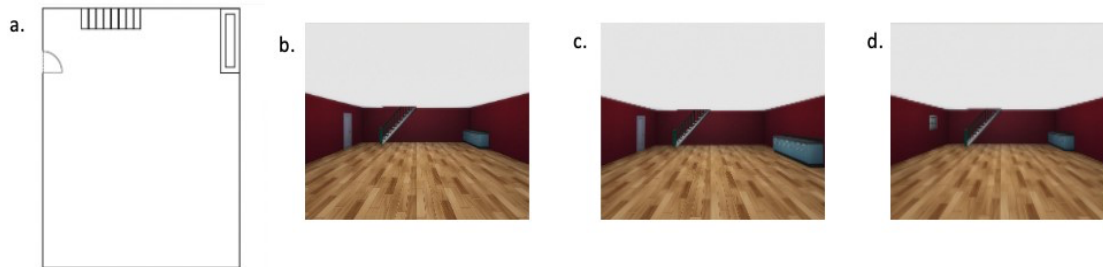
Note. a. is a location match for b. and a location mismatch for c.

### *Main Task*

**Main task stimuli.** The elements of scenes in the main task differed in object location or object identity. Half of the trials were “matches”, where all aspects of floorplan and screenshot images were the same (Figure 4.b); the other half of the trials were mismatches, where one of the elements differed in object location (Figure 4.c) or object identity (Figure 4.d).

## Figure 4

### *Main Task Stimuli.*



a is a match for b., whereas c. is a location mismatch and d. is an object mismatch.

**Design.** A full factorial 2 (Age: older adults, younger adults) x 3 (Trial type: match, object mismatch, location mismatch) design was implemented. Both image and scene types were counterbalanced within and between subjects. Participants were assigned to one of eight counterbalance conditions. Participants were shown all 288 floorplans during this study.

**Procedure.** Participants were first shown example images of location “mismatches”, object “mismatches” and matches. They then completed 288 trials in which they compared scene elements of floorplan images to those of screenshot images. During each trial, participants were shown scenes that included three different scene elements. Participants were asked “Did the floorplan match the room?” and were instructed to answer ‘yes’ or no’ as quickly and accurately as possible by clicking ‘f’ or ‘j’ on their keyboards. Following this, they completed a series of trials, which ended after 5,500 ms regardless of whether a response was given. After each trial, a fixation cross was displayed on their screens for 550 ms and consecutive trials were followed by an interstimulus interval of 1000 ms. Every 72 trials, participants were asked if they would like to take a break and were allowed to continue the study whenever they

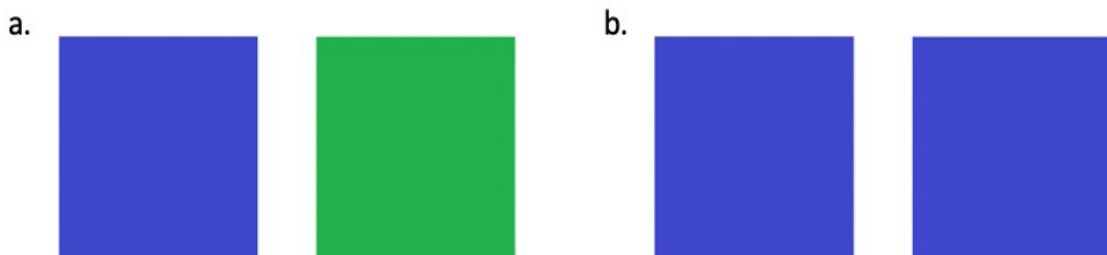
wished. The accuracy and response times of all participants were recorded and the data of participants who respond inaccurately 50 times or more were excluded from the analysis.

### ***Attention Checks***

Throughout the main task, participants completed 11 attention checks. These were evenly spread throughout the main task. Participants indicated if the images matched in colour or not by 'yes' or 'no' by clicking 'f' or 'j' on their keyboard. An attention check mismatch is shown in Figure 6.a, whereas an attention check match is shown in Figure 6.b.

### **Figure 5**

*Attention Check.*



### ***Surprise Recognition Task***

At the end of the main task, participants were given a surprise recognition task to ensure that they remembered the scene elements. They were presented with floorplan images, each with one of the four scene elements. They were asked to identify which real life element the scene elements in the floorplans represented by typing the name of each element presented to them on their screen.

### ***Questionnaires***

Participants were administered the Survey of Autobiographical Memory (2012), the Verbal-Visualizer Questionnaire (Richardson, 1977) and the Vividness of Mental Imagery Questionnaire (Marks, 1977).

The Survey of Autobiographical Memory (SAM) by Palombo et al. (2012) comprises 26 items that assess self-reported spatial, semantic, episodic, and future memory for events. Individuals rated the strength of their agreement to items such as “When I imagine an event in the future, I can picture images” on a 5-point Likert scale ranging from one (strongly disagree) to five (strongly agree). Reverse coded items were also included in the questionnaire, such as “I get lost easily, even in familiar areas”.

The Verbal-Visualizer Questionnaire by Richardson (1977) includes 30 questions with choice responses of true or false. This questionnaire asked participants about their preference or lack thereof for both verbal and visual strategies. Final scores were calculated by summing the scores of each item.

The Vividness of Mental Imagery Questionnaire (VVIQ) by Marks (1977) includes 16 mental imagery items which participants were asked to rate on a 5-point Likert scale. The scale ranged from one (perfectly clear and as vivid as normal vision) to five (no image at all, you only “know” the object).

### ***Neuropsychological Battery***

After participants completed the main study, they were asked if they would like to partake in the neuropsychological battery, a follow up study aimed to assess their cognitive skills. The results of the neuropsychological battery were not included in the current write up.

## Analyses

I analysed reaction time (RT) and accuracy using a 2 (Age: older adults, younger adults) x 3 (Trial type: match, object mismatch, location mismatch) factorial ANOVA. To support the hypothesis that older adults perform significantly poorer than younger adults on the location task, we expected a significant trial type by age interaction on Reaction Time (RT) and accuracy. Compared to younger adults, older adults were expected to have greater RT and lower accuracy on the location-based trials in contrast to the object-based trials. A-priori t-tests were used to investigate the predicted differences between age groups on the location and object trials. Any other significant effects found were followed up with t-tests.

## Results

### Analyses

A 2 (Age: younger adults, older adults) x 3 (Trial type: match, object mismatch, location mismatch) Analysis of Variance (ANOVA) was conducted to compare the effects of age and trial type, as well as their interaction, RT and accuracy. Twelve participants were screened out during the training tasks (more than 96 invalid trials) or screened out during the main task (more than 50 invalid trials). Two participants were removed from analyses because they had high error rate during the training tasks ( $z > 3$ ) or the main task ( $z > 3$ ). Follow up t-tests were used to examine any significant effects and a priori independent and paired samples t-tests were used to compare older and younger adult RT and accuracy on location and object trials.

### Reaction Time

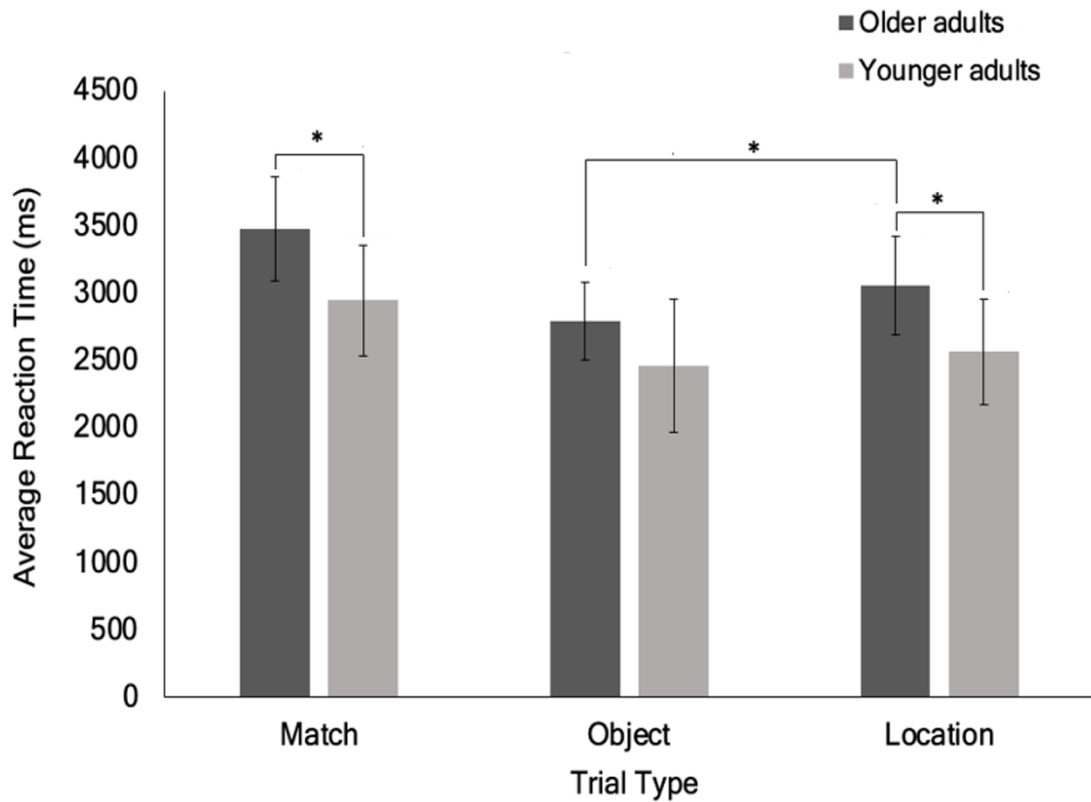
The results of the 2x3 repeated measures ANOVA showed a main effect for age  $F(1, 27) = 10.06, p = .004, \eta^2 = .72$ , and trial type  $F(2, 54) = 68.82, p < .001, \eta^2 = .72$ . The

main effect of age revealed older adults spent longer responding to stimuli than younger adults (Figure 6). There was no significant interaction between age and trial type,  $F(2, 54) = 2.0, p = .15, \eta^2 = .07$ , indicating that there was no combined effect for age and trial type on RT.

Follow up paired samples t-tests revealed that RT was significantly longer during match trials compared to object trials  $t(28) = 11.86, p = .001$  and location trials  $t(28) = 7.26, p = .001$ . A priori independent samples t-test revealed that the RT of older adults was significantly longer than younger adults in the location trials  $t(27) = -3.33, p = .003$  but not the object trials  $t(27) = -2.04, p = .05$ . A priori paired samples t-tests revealed that younger adult RT did not significantly differ between object and location trials  $t(14) = -1.74, p = .11$ . In other words, younger adults spent a similar amount of time responding to the object and location trials (Figure 6). Furthermore, older adult RT was significantly longer during the location trials compared to the object trials  $t(13) = -3.22, p = .007$ .

**Figure 6**

*Average Reaction Time of Younger and Older Adults across Trial Type*



*Note.* \* Indicates significant independent and paired samples t-tests.

### **Accuracy**

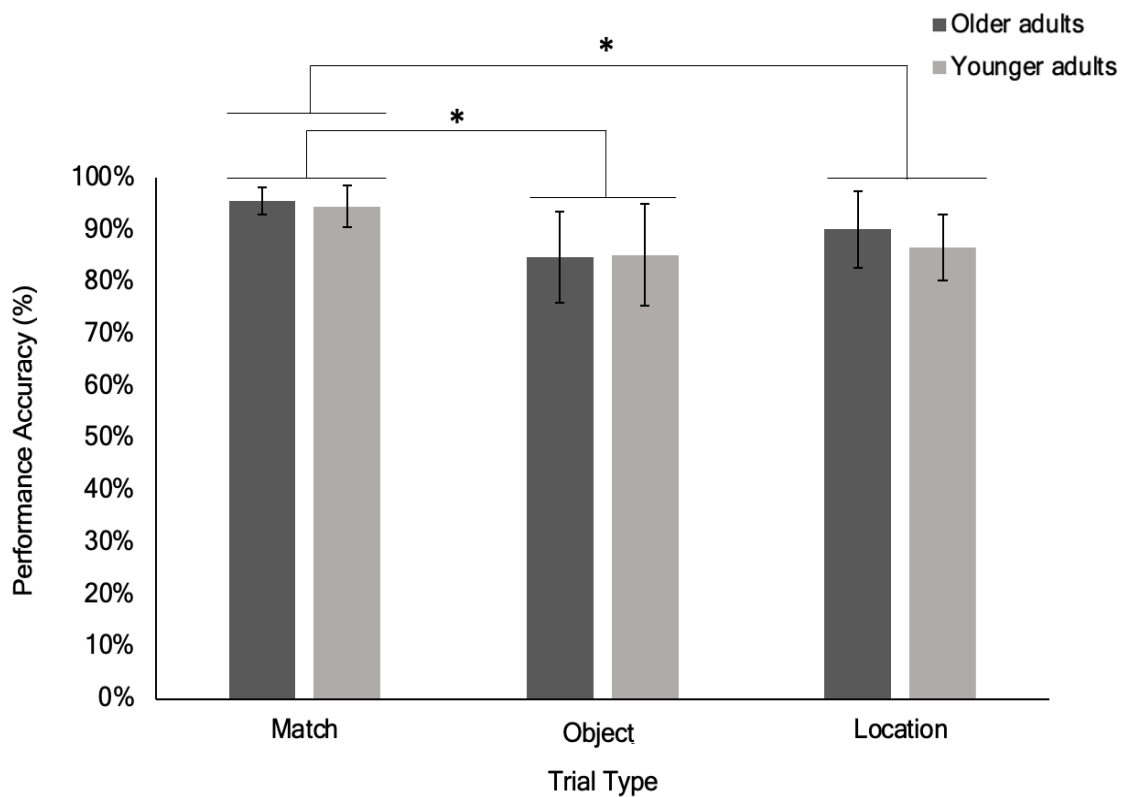
The results of the 2x3 repeated measures ANOVA showed a main effect for trial type  $F(2, 54) = 28.00, p < .001, \eta^2 = .51$  but not age  $F(1, 27) = 0.25, p = .62, \eta^2 = .01$  for accuracy. Older adults and younger adults did not significantly differ in accuracy scores across trial types (Figure 7). There was no significant interaction between age and trial type  $F(2, 54) = .75, p = .48, \eta^2 = .03$ , indicating that there was no combined effect of age and trial type on accuracy.

Follow up paired samples t-tests revealed that accuracy was significantly greater for the match trials compared to the object trials  $t(28) = 6.68, p = .001$  and location trials

$t(28) = 6.21, p = .001$ . A priori independent samples t-test revealed that the accuracy of younger and older adults did not significantly differ across location trials  $t(27) = -1.08, p = .29$  or object trials  $t(27) = -22, p = .83$ ; similarly, younger adult accuracy did not significantly differ between object and location trials  $t(14) = -.92, p = .37$  nor did older adults  $t(13) = -1.94, p = .08$ .

**Figure 7**

*Average Accuracy of Younger and Older Adults across Trial Type*



*Note.* \* Indicates significant independent and paired samples t-tests.

## Discussion

The current study examined age-related differences in spatial processing using a novel task with few mnemonic demands. A significant interaction between age and trial type for RT and accuracy was expected. In other words, I predicted that older adults would spend significantly more time and be significantly less accurate than younger adults on the location trials compared to object trials. Analyses of performance on trial types indicated that older adults did not perform significantly worse than younger adults on location-based tasks compared to object-based tasks; thus, the predicted interaction between age and trial type was not found for either RT or accuracy.

Older adults were expected to be significantly less accurate than younger adults on the location trials compared to the object trials. There was no difference between the age groups on accuracy across the trial types, but there was a significant difference in trial type, with the match trial being the most accurate. When the predicted difference was inspected further, there was no difference between the age groups on accuracy across the location and object trials. Therefore, the predicted difference for accuracy between age groups for the location trials was not found. However, the prediction that age groups would perform similar on the object trials was supported.

Older adults were expected to spend significantly longer reacting than younger adults to the location trials compared to the object trials. There were differences between the age groups on RT across the trial types, indicating that older adults spent longer reacting than younger adults, but spent the longest reacting to the match trials. When examining these effects further, it was found that older adults were slower than younger adults on the location trials but not the object trials. Moreover, both age groups spent a

similar amount of time reacting to the object and location trials, but older adults were significantly slower on the location trials compared to the object trials. Therefore, the prediction that older adults would spend significantly longer than younger adults when reacting to the location trials compared to the object trials was supported.

Although older and younger adults achieved similar accuracy on each trial type, the small effect found for older adult RT on location trials indicates the presence of a subtle spatial processing deficit. Therefore, the hypothesis that older adults would perform significantly worse than younger adults on the location-based tasks compared to the object-based tasks was partially supported. There was also found to be no difference between older and younger adult performance on the object trials, indicating that both groups processed object information similarly. Therefore, the hypothesis that older and younger adult performance would not significantly differ on object trials was supported.

One interpretation of these findings supports mnemonic accounts of the hippocampus: perhaps older adults do not have trouble forming associations between the elements of a scene but instead have difficulty holding many aspects of a scene constant in memory at once. Given that mnemonic processing was controlled for, this would explain why older adults did not significantly differ from younger adults in terms of accuracy on the object and location-based trials. However, mnemonic accounts cannot explain why there were subtle differences found in RT for older adults only on the location trials.

Since accuracy was similar across all trial types and age groups in our study, this indicates that no one trial type was more difficult than the others. Despite this, older adults still had significantly lower RT on the location trials. The subtle spatial processing deficits

found may be indicative of a speed-accuracy trade-off for older adults on the location-based tasks. Literature suggests that older adults are more likely to spend more time on tasks they find difficult to compensate for poor performance (Forstmann et al., 2011; Salthouse, 1979). Therefore, the older adults in our study may have been compensating for poorer accuracy on the location trials by allocating more time to them.

All the older adults included in this study may have been particularly healthy with preserved cognitive function. More than half of our sample was under the age of 65 and all had exceptional computer ability. Therefore, perhaps because individuals were particularly cognitively healthy, they had greater cognitive flexibility which allowed for efficient spatial processing (Ladyka-Wojcik et al., 2021). Given that cognitive flexibility in healthy aging has been associated with greater hippocampal volumes, this may also help to explain why the accuracy of older adults and younger adults did not differ on the location and object-based tasks and the deficits observed were subtle (Hardcastle et al., 2020).

Furthermore, there was found to be no difference between older and younger adult RT or accuracy on object trials. These findings are comparable to those of Tran et al. (2021), who also found no difference in younger and older adult performance when recognizing changes in object identity. As previous studies have suggested, the hippocampus is not involved in forming complex object representations (Barens et al., 2012; Lee et al., 2005; Persson et al., 2012). Therefore, since this process is not affected by aging, this explains why older and younger adults did not differ during object discrimination tasks. Despite older adults having greater RT than younger adults during the location trials, they took no longer than younger adults when responding to object-

based trials and still performed similarly (Salthouse, 1996). Thus, suggesting that object-based tasks may not have been as demanding. Conversely, the location-based tasks may have been more challenging because these require forming associations between the elements of a scene. Associative processing has been related to activity in the hippocampus, which has been shown to be attenuated by aging. Therefore, location tasks may have been more demanding for older adults because they placed a greater demand on the hippocampus.

Altogether, similar accuracy scores between groups and across trials could be partially explained for by differences in RT. Though cognitive flexibility may be partial to healthy aging, perhaps longer RT in older adults during the location-based trials are early indications of later cognitive decline during these tasks. Cognitive processing speed has been found to be a strong predictor of age-related cognitive decline on many tasks, including daily activities (Salthouse & Ferrer-Caja, 2003; Wadley et al., 2021). Furthermore, deficits in cognitive processing speed have been strongly associated with the progression of mild cognitive impairment. Thus, while older adults generally have slower processing speed than younger adults, pronounced age-related RT to the location-based trials may provide early insight into what could be later cognitive decline.

The current study contributes to knowledge surrounding age related decline in spatial processing by providing insight into what this looks like in healthy older adults while using a novel task that minimizes mnemonic demands. Though the hippocampus has been implicated in memory, spatial processing and healthy age-related decline, no study has looked at the relationship between spatial processing and healthy aging with few

mnemonic demands. Thus, the results of this study may suggest that healthy older adults experience subtle spatial processing deficits.

The relationship between processing speed and accuracy scores during perceptual tasks should be examined further, possibly with an older group of healthy participants using a longitudinal design. As such, though our sample of older adults ranged from 60-85, it should be noted that most of our sample was closer to the age of 60. Thus, perhaps future studies should also examine the predictive value of processing speed in the age-related decline of spatial processing and whether this is associated with an age of onset. Examining this relationship may also tell us more about the nature of spatial processing decline in individuals with mild cognitive impairment, given that decline in processing speed and episodic memory impairment are major symptoms of this condition (Haworth et al., 2016; Nordahl et al., 2005).

### **Limitations**

Participants completed this study online using their own monitoring systems, making them subject to attentional distractions in their personal environment. Though this study controlled for this as much as possible by implementing attentional checks and screening out participants with over 50 incorrect trials, it is impossible to ensure that all participants remained distraction free throughout the study. Furthermore, though recruitment through the online platform Prolific ensured participant anonymity, it is entirely possible that participants were not truthful about their age, nationality, or other pre-screening factors. To control for the above limitations in future studies, recruiting participants only through word of mouth and having them complete the study in a controlled in-person environment may be recommended to minimize confounds.

## **Conclusion**

In conclusion, healthy older adults exhibited subtle spatial processing deficits during the location trials when minimizing mnemonic demands. Furthermore, there was no difference between younger and older adults in terms of object processing. The subtle processing deficits that were found help us to better understand the processes behind cognitive impairment and how this occurs with aging. Our findings indicate the presence of a slight associative processing deficit in healthy older adults, which fits in with larger theories proposing that this process is compromised by aging. Furthermore, though brain activity was not examined in the current study, our findings fit in with the role of the hippocampus in spatial processing.

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## Appendices

### Appendix A

#### Informed Consent



#### Age-related differences in spatial relational processing

Undergraduate Researcher: Ms. Hannah Landry

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. Landry, 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](mailto: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](mailto:reb@mta.ca).

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

## Appendix B

### Pre-screening questionnaire

Please answer the following questions truthfully

Top of Form

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

Bottom of Form

### Debriefing



Age-related differences in spatial relational processing

Ms. Hannah Landry, 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](mailto: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](mailto:reb@mta.ca).