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Age-related Similarities and Differences in Monitoring Spatial Cognition

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Abstract

Spatial cognitive performance is impaired in later adulthood but it is unclear whether the metacognitive processes involved in monitoring spatial cognitive performance are also compromised. Inaccurate monitoring could affect whether people choose to engage in tasks that require spatial thinking and also the strategies they use in spatial domains such as navigation. The current experiment examined potential age differences in monitoring spatial cognitive performance in a variety of spatial domains including visual spatial working memory, spatial orientation, spatial visualization, navigation, and place learning. Younger and older adults completed a 2d mental rotation test, 3d mental rotation test, paper folding test, spatial memory span test, two virtual navigation tasks, and a cognitive mapping test. Participants also made metacognitive judgments of performance (confidence judgments, judgments of learning, or navigation time estimates) on each trial for all spatial tasks. Preference for allocentric or egocentric navigation strategies were also measured. Overall, performance was poorer and confidence in performance was lower for older adults than younger adults. In most spatial domains, the absolute and relative accuracy of metacognitive judgments was equivalent for both age groups. However, age differences in monitoring accuracy (specifically relative accuracy) emerged in spatial tasks involving navigation. Confidence in navigating for a target location also mediated age differences in allocentric navigation strategy use. These findings suggest that with the possible exception of navigation monitoring spatial cognition may be spared from age-related decline even though spatial cognition itself is impaired in older age.

Keywords

Metacognition; monitoring; confidence; spatial cognition; navigation; aging

The ability to encode, access, manipulate, and reason about the location and orientation of objects and places in one's environment – termed spatial cognition – plays a key role in many tasks including map reading, remembering object locations, navigation, and learning in science, technology, engineering, and mathematics (STEM) domains (Uttal & Cohen, 2012; Wai, Lubinski, & Benbow, 2009). Given the contributions of spatial cognition to many daily tasks and its susceptibility to age-related decline (Klencklen et al., 2012; Moffat,

2009), it is important that people can accurately monitor and evaluate their own spatial cognitive performance because one's perceptions of their spatial performance may influence uses of spatial strategies and decisions to engage in tasks that require spatial thinking. For instance, students who are underconfident in their spatial ability may decide not to pursue STEM course work or careers (Ehrlinger & Dunning, 2003). Likewise, inaccurate perceptions of spatial skills could affect the strategies that older adults in the aging STEM workforce use to solve novel spatial oriented problems¹.

Inaccurate monitoring may also have implications for older adults beyond learning and reasoning in STEM domains. Confidence in one's spatial cognitive abilities could adversely affect (1) the strategies they use during navigation, (2) the likelihood they are willing to adopt new technologies that require interacting with spatial oriented displays (e.g., computers, GPS devices, smartphones, etc.), or (3) even decisions to use effective imagery-based mnemonics to remember important information. The current experiment examined whether younger and older adults can accurately monitor their spatial cognitive performance and whether metacognitive monitoring accuracy for spatial cognition is susceptible to age-related cognitive decline.

Although extensive research has evaluated the effects of aging on spatial cognition (Borella et al., 2014; Hertzog & Rypma, 1991; Klencklen, Despres, & Dufour, 2012; Moffat, 2009; Techentin, Voyer, & Voyer, 2014), only a few experiments have evaluated either younger or older adults' metacognitive monitoring accuracy in spatial domains. The limited research available has focused almost exclusively on younger adults in visual search (Redford et al., 2011) and mental rotation (i.e., spatial orientation, Cooke-Simpson & Voyer, 2007; Estes & Felker, 2012). One exception is Thomas, Bonura, Taylor, and Brunye (2012) who examined age differences in monitoring visual spatial working memory. They found that the relative accuracy of metacognitive judgments were worse for older adults than younger adults when objects and locations were presented briefly but not under longer presentation conditions. Their results suggest that age-related declines in visual-spatial working memory may have negative effects on older adults' monitoring of spatial cognition.

Metacognitive monitoring is presumably a heuristic process (Dunlosky & Tauber, 2014; Koriat, 1997, Schwartz, Benjamin, & Bjork 1997). People use relatively simple heuristics to infer the quality of their memory processes in the verbal domains typically examined for metacognitive research. They might apply naïve theories about how item characteristics such as semantic relatedness or perceptual features for to-be learned material will influence memory processes or they might rely on other cues including retrieval fluency of target information during judgments (Benjamin, Bjork, & Schwartz 1997; Hertzog et al, 2002; Mueller et al., 2014; Rhodes & Castel, 2008). It is unclear what heuristics people use when monitoring spatial cognition. However, one hypothesis derived from the results of Thomas et al. (2012) is that monitoring the quality of spatial cognitive processes may be susceptible to error due to declines in working memory processes in older age. Certainly, spatial cognitive processing by its very nature requires one to maintain and manipulate visual spatial

¹The National Science Board (2016) reports that 34% of the STEM workforce in 2013 was made up of older adults between ages 51 and 75. The report does not cover people over age 75.

information in working memory (Miyake et al., 2002) and hence, one might assume that monitoring the quality of spatial processing and corresponding visual-spatial representations may be too cognitively demanding for older adults.

The current experiment evaluated the effects of aging on monitoring accuracy of spatial cognition more extensively. Multiple spatial domains were examined including visual-spatial working memory, spatial orientation (mental rotation), spatial visualization (mental transformation of objects into new forms), and spatial navigation. We chose to examine multiple spatial domains because spatial cognition is a multifaceted construct encompassing several related but unique cognitive faculties (Carroll, 1993; Hegarty & Waller, 2005; Michael et al., 1957). These different cognitive faculties are uniquely associated with performance in many everyday tasks. Visual spatial working memory is associated with remembering the spatial locations of objects as well as one's ability to generate complex mental images (Mammarella, Pazzaglia, & Cornoldi, 2006). Spatial visualization abilities predict success in STEM domains (Wai et al., 2009) and usability issues for older adults with computer-based technologies (Kelley & Charness, 1995; Ziefle & Bay, 2006). Spatial orientation skills are associated with wayfinding, map reading, and other tasks that requires one to mentally reorient themselves or objects in their environment (Kozlowski & Bryant, 1977; Thorndyke & Goldin, 1983). Lastly, navigation incorporates the above processes as well as other unique processes to aid in goal directed movement throughout one's environment (Moffat et al., 2007).

In the current experiment, our main focus was on the effects of aging on monitoring accuracy in each spatial domain. However, we also leveraged the navigation tasks we used to test a hypothesis about how confidence in spatial memory for locations affects the strategies that older adults use during navigation.

Older adults typically prefer using egocentric strategies during navigation that are person centered and response based (e.g., turn left, then right). In contrast, younger adults prefer allocentric strategies which use a cognitive map to reference different locations in the environment for navigation (Driscoll et al., 2005; Iaria et al., 2009; Rogers, Sindone, & Moffat, 2012; Wiener et al., 2013). Age differences in navigation strategy preference have been attributed to declines in the processes and brain structures (e.g., decreased hippocampal volume) that support the development of a cognitive map of one's environment (Moffat, Elkins, & Resnick, 2006; Rogers, Sindone, & Moffat, 2012). However, it is also possible that preferences for using egocentric strategies are in some cases strategic. That is, if older adults are underconfident in their memory for locations, they may be reluctant to use navigation strategies that involve direct retrieval of location information about the environment. The current experiment evaluated this hypothesis by examining whether confidence in memory for a key goal location in a virtual navigation task mediated age differences in allocentric strategy preferences.

In the current experiment, younger (age 18 to 25) and older adults (age 60 to 82) completed a battery of spatial tests and made metacognitive judgments. These tasks included assessments of visual spatial working memory (spatial span task), spatial orientation (2d and 3d mental rotation), spatial visualization (paper folding), navigation (virtual Morris water

maze), and a cognitive mapping task. Participants' preference for allocentric navigation strategies were also examined using a Y-maze navigation task.

Method

Participants.

Thirty four older adults from the Atlanta metropolitan area (8 females, 26 males, M Age = 73 years old, Range 60–82) and 35 younger adults from The Georgia Institute of Technology (8 females, 27 males, M Age = 20 years old) participated in this experiment. Older adults received \$10 per hour and compensation for travel expenses and younger adults received course credit for participation. All older adults had self-reported good health and computer proficiency. The majority of older adults were college educated (53% had a bachelor's degree, 35% had a graduate level degree, and 12% had a high school diploma). Age groups did not differ in performance on the Mini Mental Status Exam (MMSE) (YAs: $M = 29.20$, $SE = .23$; OAs: $M = 28.97$, $SE = .20$), $t < 1$, and older adults scored higher on the Advanced Vocabulary Test (Ekstrom et al., 1976) than did younger adults, $t(67) = 7.87$, $p < .001$. An eye exam administered before the experiment indicated that all but 1 younger adult and 5 older adults in our sample had at least 20/40 corrected vision. All participants' data were included in our sample because we were primarily interested in monitoring accuracy which is independent of performance and there was no relationship between visual acuity and monitoring accuracy in the current experiment. Visual acuity was associated with older adults' performance on the 2d mental rotation test ($r = .43$, $p < .05$) and the spatial span task ($r = .48$, $p < .01$). However, it was not correlated with performance on any other task.

Materials & Procedure.

All tasks except when noted otherwise were administered on a computer using a custom program displayed on a widescreen computer monitor. All participants were tested individually. After obtaining informed consent, participants completed a written demographic survey. Participants then completed a standard eye exam, the Ishihara color blindness test, a spatial memory self-efficacy questionnaire (SSEQ; West, Welch, & Knabb, 2002), and the MMSE. No age differences were present for average confidence ratings ($M = 73.23$, $SE = 1.64$) for the SSEQ, $t < 1$.

The remaining experimental protocol was administered in the following order: (1) spatial span task, (2) paper folding test, (3) advanced vocabulary test, (4) 2d mental rotation test, (5) 3d mental rotation test, (6) computer experience questionnaire, (7) navigation tests, and (8) cognitive mapping test. We chose to keep task order fixed because it allowed us to examine individual differences across spatial tasks (for rationale, see Carlson & Moses, 2001) and because metacognitive monitoring is typically not affected by fatigue (Baranski, 2007). The choice of task order was arbitrary with the exception of the navigation tasks which were administered near the end the experimental protocol because these tasks can cause motion sickness. The entire test battery took approximately 2 hours for older adults to complete and 1 hour and 30 minutes for younger adults to complete. Each task is described in detail below.

Visual Spatial Working Memory.

A spatial span task containing 50 trials was administered to measure monitoring accuracy of visual spatial working memory. On each trial participants studied a 5×5 black colored grid in which 3 to 7 random grid cells were presented in white (load manipulation). Load trials were presented in blocks of 5 trials and the load order was always randomized. Participants were instructed to remember where the white cells were located. Younger adults studied grids for 1 second and older adults studied for 3 seconds. Older adults were given more time to study on each trial so that we could eliminate any potential differences in relative accuracy that would occur due to failure to establish an initial representation of the items. Thus, if monitoring accuracy differences occur in this task, we could more confidently conclude that these differences reflect differences in monitoring processes and not memory quality.

Immediately after time expired to study on a given trial, a 500 ms perceptual mask was presented. Participants were then prompted to make a judgment of learning (JOL) by rating how confident they were that they would remember the pattern they just studied. Participants rated their confidence by moving a slider to any value between 0 (Not at all confident) and 100 (Extremely confident). The starting location of the slider for all metacognitive judgments was always set to the mid-point of the scale (i.e., 50) to begin each rating trial. After moving the slider, participants pressed a button to indicate they were finished. A new screen appeared for 1 sec that instructed participants to get ready for the test. Next participants were tested on the previous pattern using 5×5 black grid. Participants clicked on cells of this grid to indicate where they remembered the white boxes were located. When a cell was clicked its color was changed to white. Participants were allowed to 'unclick' cells if they desired to do so and the trial ended after they clicked a button labeled done. There was no time limit to complete test trials and participants were not given feedback about their performance on any trial. After reporting a response, a screen instructing participants to get ready for the next trial was presented for 1 sec.

Spatial Visualization.

A modified version of the VZ-2 paper folding task was administered to assess monitoring differences in spatial visualization (French, Ekstrom, & Price, 1985). The task consisted of 20 trials presented in a randomized order for each participant. There was no time limit for completing each trial. On each trial, participants viewed a drawing of a paper folded one to three times. They were instructed to visualize that a circular hole was punched into the folded paper and then to select among 5 response options the piece of paper that contains the hole located in the correct locations when unfolded. Participants selected a response option by clicking a button located below each option. After selecting their response, they made a confidence judgment (CJ) about the accuracy of their selection by moving a slider to any value between 0 (not at all confident) and 100 (extremely confident). Participants then viewed a screen for 2 seconds instructing them to get ready for the next trial. No feedback was provided about performance on the previous trial. The procedure then repeated until participants completed all 20 trials. After completing all 20 trials, participants made a global confidence judgment regarding the percentage of trials they believed they correctly completed by moving a slider to a value between 0% and 100%.

Spatial Orientation.

Monitoring differences in spatial orientation were examined using a modified version of Thurstone and Thurstones (1947) Spatial Relations Test which involved 2d mental rotation and a modified version of the 3d mental rotation task developed by Vandenburg and Kuse (1978). The 2d and 3d mental rotation tasks were administered separately and trial order was randomized. The 2d mental rotation task consisted of 30 trials in which participants viewed a 2d drawing and then 5 response options containing either identical drawings rotated into a different orientation or similar but different drawings presented in various orientations. The goal is to select the option(s) that are the same as the target drawing.. The 3d mental rotation task involved 24 trials in which a 3d drawing is presented with 4 response options. Two of the 4 response options were the same object rotated on the x, y, or z plane into a different orientation. Participants were instructed to select the two response options that were identical but rotated differently on each trial by clicking a check box below each one. After selecting response options in both tasks, participants clicked a button to indicate they were finished. They then were prompted to make a CJ on a scale from 0 to 100 using the following prompt: "How confident are you that you selected the correct figures?". After moving the slider to make their CJ, they were instructed to get ready for the next trial and following a 1 s delay the procedure above repeated until all trials were completed. Participants were then instructed to make a global CJ in the same manner as the paper folding task. Participants were not provided performance feedback at any point during these tasks.

Computer Experience Questionnaire.

A computer experience questionnaire was administered to allow us to control for age differences in computer experience on navigation performance. Participants were asked to rate (a) their mount of experience using a computer, (b) playing computer (video) games, and (c) playing computer games that specifically involve navigating through 3-D environments (e.g., flight simulators, driving simulators, Doom, ect.). Participants rated their experience using a 7 point Likert scale where 1 indicated they had no experience and 7 indicated they had daily experience.

Spatial Navigation.

The navigation environments were created with Unreal Tournament 2003 (Epic Games, Rockville, MD, USA). Movement was controlled using a joystick for all tasks. The navigation protocol consisted of 4 phases: Joystick practice, a joystick competency test, a virtual Y-maze, and virtual Morris Water Maze (vMWM). All tasks were presented from a first person perspective. Participants were first trained to use the joystick in a practice environment. The experimenter demonstrated how to use the joystick for moving forward, backward, and turning. Next, participants practiced moving in the environment and were allowed to freely explore it. After participants were comfortable using the joystick, they were instructed to proceed down a hallway to a designated goal area. After reaching the goal area, they completed a speed test in which they had to navigate to the end of a meandering hallway . There were no decisions about which way to turn in this task, participants simply had to quickly follow the hallway.

The virtual Y-maze was used to assess participants' preference for allocentric vs. egocentric navigation strategies using methodology from Rogers, Sindone, and Moffat (2012). The Y-maze task consisted of a learning phase and a strategy probe phase. For the learning phase, participants began in the same area of a y-shaped maze illustrated in Figure 1. They were instructed to move forward and then proceed down either the left or right hallway to find a goal location. Participants were only allowed to move within the maze, but they could view cues in the larger environment while navigating. When they reached the end of the correct hallway, a pleasant tone was triggered to indicate they found the goal location. If participants went to the incorrect location, an unpleasant tone (buzzing sound) was triggered. After reaching the correct or incorrect location, participants were automatically moved to the starting location to begin the next trial. The learning phase continued until participants made 5 consecutive correct responses. Next participants completed a strategy probe trial in which the starting location was altered without altering the cues in the environment. . Participants who turned left on the probe trial (making the same response they had done on learning trials) were classified as using an egocentric strategy and participants who turned right (moving to the same absolute spatial location as in the learning trials) were classified as using an allocentric strategy (Rogers, Sindone, and Moffat, 2012).

Next, participants completed a vMWM task which is illustrated in Figure 2. The goal of the vMWM was to find a hidden platform submerged in a larger circular pool of water. The platform was always located in the same location of the pool and when participants intercepted the platform, it became visible, lifting them out of the water for 10 seconds. Following this 10 s delay, the next trial began. On each trial, participants started in a random location of the pool and navigated to the platform location. The task began with two practice trials that occurred in a different pool from the test phase. They were instructed that the platform in the practice environment would not be the same as the test environment. Participants were given unlimited time on both practice trials to find the platform location.

After completing the practice phase, participants completed the same task in a new environment. However, in this new environment they had only 60 seconds to find the platform on each trial and before starting each trial, they made performance estimates about how long they thought it would take them to find the platform on that trial. They responded with any value between 0 and 60 seconds. This performance estimate was made at the starting location of the trial and hence participants could view their present location and use this information to make their estimate. After making an estimate, they began the trial which continued until participants either found the platform location or time expired.

Participants time estimates served as the primary measure of monitoring accuracy for the vMWM task. Accurately estimating time requires participants to know where the platform is located, calculate the distance between the starting location and platform, and estimate one's speed of movement through the environment. Thus, theoretically this estimate could be influenced by confidence in spatial memory, confidence in distance estimation, and confidence in navigation ability.

After completing 10 trials, participants completed a visible platform trial. For this trial, the platform location was marked with flags on each of its corners and participants were

instructed to navigate to the platform as quickly as possible. Participants did not make time estimates for the visible platform trial. The purpose of this trial was to ensure adequate visuomotor control such that participants could navigate to the platform, if they knew where it was located. All participants were able to do so.

After completing the vMWM, participants completed a modified version of the cognitive mapping task administered by Moffat and Resnick (2002). They were first instructed to imagine that they viewed an overhead map of the room where the pool used in the vMWM task was located. They were instructed that the location of the platform would not be visible on this map. They were asked to rate how confident they were that they could identify the true location of the platform using this map by moving a slider to any value between 0 (not at all confident) and 100 (extremely confident). After rating their confidence, they completed 3 trials in which they viewed 3 different overhead maps of the room containing the pool. The first map contained only distal/boundary cues of the room (only the outer wall of the room and the pool were visible), the second contained only proximal cues (objects in the room and the pool were visible, but no walls), and the third contained both distal and proximal cues (see Figure 2, right panel). On each trial, participants clicked on the location where they believed the platform was located. After clicking, a platform appeared in the selected location and participants could adjust the platform location further using the mouse. They then clicked a button to move on. Next, they made a CJ about whether the platform was placed in its true location and a distance deviation estimation judgment. For the distance deviation estimate, they were asked, "How far do you believe the true location of the platform is from the location you selected?". Participants made this estimate by moving a slider to a value between 0 (not very far) and 100 (Very far away).

Results

Mean Performance Measures and Metacognitive Judgments

Given that age differences in performance, metacognitive judgments, and monitoring accuracy were examined across 6 different spatial tasks (spatial span task, 2d mental rotation, 3d mental rotation, paper folding, vMWM, and cognitive mapping), we used a Bonferroni correction to set a more conservative alpha level for rejecting the null hypothesis about age differences for these measures ($p < .008$). For all other measures, we used an alpha level of $p < .05$.

Visual-Spatial Working Memory.

The mean percentage of patterns correctly recalled in the spatial span task and mean JOLs as a function of memory load condition are presented in Figure 3 for younger and older adults. A 2 (age group) x 5 (Memory Load) repeated measures ANOVA with a planned comparison for linear trend effect for load condition (see Hertzog, 1994) revealed a significant effect for age group, $F(1,67) = 83.10$, $MSE = 9.35$, $p < .001$, $\eta_p^2 = .55$, and significant linear trend effect for load condition, $F(1,67) = 276.91$, $MSE = 8.66$, $p < .001$, $\eta_p^2 = .81$. The age x memory load linear trend interaction was not significant, $F(4,67) = .21$, $MSE = .05$, $p = .21$, $\eta_p^2 = .02$. Memory performance decreased as memory load increased and performance overall was higher for younger than older adults.

With regard to JOLs, younger adults were more confident in their memory for the spatial patterns than were older adults, $F(1,67) = 35.03$, $MSE = 43653.91$, $p < .001$, $\eta_p^2 = .34$. The range of JOLs that individuals reported were on average higher for older adults ($M = 11$ to 90) than for younger adults ($M = 29$ to 99), $t(67) = 2.05$, $p < .05$, $d = .44$. Both age groups confidence decreased as memory load increased, $F(1,67) = 236.86$, $MSE = 29268.82$, $p < .001$, $\eta_p^2 = .78$. These main effects were qualified by an Age Group x Memory Load linear trend effect, $F(1,67) = 7.27$, $MSE = 898.22$, $p < .05$, $\eta_p^2 = .10$. This interaction occurred because older adults' confidence decreased at a higher rate as load increased (Slope: $M = -7.65$, $SE = .64$) than did younger adults' confidence ($M = -5.37$, $SE = .55$), $t(67) = 2.70$, $p < .05$, $d = .65$.

Next, we evaluated whether age groups differed in their use of retrieval fluency when making JOLs by computing a γ correlation for each individual between their JOLs and their retrieval latency (the response time in milliseconds during each recall trial). This analysis revealed that both younger (Younger: $M = .08$, $SE = .01$) and older adults' JOLs ($M = .08$, $SE = .01$) were equally sensitive to retrieval fluency, $t(67) = 1.43$, $p = .16$, $d = .34$. Thus, younger and older adults used at least one similar cue to a similar extent to make their JOLs.

Spatial visualization and Spatial Orientation.

Mean performance, CJs, and global CJs for the 2d mental rotation task, 3d mental rotation task, and paper folding test are presented in Table 1 with their corresponding independent samples t-tests. Younger adults correctly completed more trials of the 2d mental rotation task, 3d mental rotation task, and paper folding test than did older adults. Younger adults' item level CJs were also higher than older adults for the 3d mental rotation, and paper folding test, but not for the 2d mental rotation test. On average, older adults responded with a higher range of CJs for trials on the paper folding test ($M = 17$ to 87) than did younger adults ($M = 36$ to 96) but these group differences were not statistically significant, $t(67) = 1.84$, $p = .07$, $d = .44$. The range of CJs that younger and older adults reported were similar in both the 2d mental rotation (Older adults: $M = 46$ to 88 ; Younger adults: $M = 55$ to 94) and 3d mental rotation test (Older adults: $M = 32$ to 77 ; Younger adults: $M = 48$ to 90), $ts < 1$. Finally, older adult's global CJs were also lower than younger adults for all tasks.

The effects of fluency on monitoring judgments were evaluated by computing gamma correlations between response times for trials of each spatial task and participants' CJs. Gamma correlations differed significantly from zero for the 2d mental rotation (Younger: $M = -.24$, $SE = .05$; Older: $M = -.37$, $SE = .05$), 3d mental rotation (Younger: $M = -.28$, $SE = .04$; Older: $M = -.27$, $SE = .05$), and paper folding tests (Younger: $M = -.49$, $SE = .04$; Older: $M = -.50$, $SE = .05$) which suggests that processing fluency was a cue that both age groups used to monitor their performance, $ts > 4.99$. There were no age differences in the influence of processing fluency on CJs for the 3d mental rotation and paper folding tests, $ts < 1$. However, older adults appeared to rely more on processing fluency as a cue to monitor their performance in the 2d mental rotation test than younger adults but these group differences were not statistically significant, $t(67) = 1.88$, $p = .07$, $d = .34$.

Spatial Navigation and Place Learning.

The proportion of trials that participants located the platform within the 60s time limit were computed to examine navigation accuracy in the vMWM. Younger adults' accuracy was nearly perfect ($M = .97$, $SE = .01$) and significantly higher than older adults' accuracy ($M = .73$, $SE = .23$), $t(62) = 5.62$, $p < .001$. Overall, younger adults found the platform location quicker ($M = 21.37$ sec, $SE = 1.46$) and they estimated their navigation time would be shorter ($M = 13.45$ sec, $SE = .116$) than did older adults (Actual time: $M = 41.98$, $SE = 2.62$; Estimated time: $M = 31.33$, $SE = 2.80$), $t_s > 6.15$. These group differences in speed, $F(1,63) = 17.25$, $MSE = 241550.90$, $p < .001$, $\eta_p^2 = .20$, accuracy, $F(1,63) = 10.11$, $MSE = .29$, $p < .01$, $\eta_p^2 = .14$, and estimated navigation time, $F(1,63) = 16.77$, $MSE = 221985.45$, $p < .001$, $\eta_p^2 = .22$, were still significant after controlling for age differences in self-rated computer experience (as measured by the computer experience questionnaire). Thus, age differences in navigation in the virtual Morris water maze cannot be accounted for by age differences in experience using computers and playing video games.

The mean time estimates and mean actual time duration in seconds for locating the platform (or time expiring) on each trial is presented in Figure 4 for both age groups. Linear slopes were computed to evaluate changes in navigation estimates and actual navigation duration across trials. Younger adults navigation time decreased across trials (actual time slope: $M = -3.13$, $SE = .36$), $t(32) = 8.65$, $p < .001$, and their navigation time estimates also predicted this decrease (Estimated time slope: $M = -1.89$, $SE = .25$), $t(32) = 7.54$, $p < .001$. A similar pattern was present for older adults, but actual time slopes ($M = -1.12$, $SE = .62$), $t(29) = 1.79$, $p = .08$, and the estimated time slopes (older adults: $M = -.77$, $SE = .43$) did not differ from zero, $t(29) = 1.80$, $p = .08$. Younger adults' actual time and estimated time slopes were both significantly larger than older adults, $t_s > 2.31$.

After completing the vMWM, younger adults ($M = 73.70$, $SE = 3.20$) were more confident than older adults ($M = 52.93$, $SE = 5.45$) that they could correctly identify the location of the platform from the water maze on an overhead map, $t(61) = 3.36$, $p < .01$, $d = .84$. Memory for the actual platform location in the vMWM was evaluated in the cognitive mapping task by computing (a) the percentage of overlap between the true location of the platform and participants' selected location (termed percentage overlap) and (b) the distance in pixels between the center of the true platform location and the center of selected platform location (termed distance deviation).

Mean performance measures, CJs following each trial, and distance deviation estimates following each trial are presented in Table 2 for trials where only distal cues were present on the map, trials where only proximal cues were present on the map, and trials where both types of cues were present. We computed separate 2 (age group) $\times$ 3 (cue type: distal, proximal, or both) repeated measures ANOVAs for each measure in Table 2. On the performance measures, the percentage overlap between the selected platform location and the true platform location was higher for younger adults than for older adults, $F(1,61) = 27.85$, $MSE = 21001.62$, $p < .001$, $\eta_p^2 = .31$. The distance between the selected platform location and the true location was also larger for older adults than for younger adults, $F(1,61) = 73.99$, $MSE = 124172.07$, $p < .001$, $\eta_p^2 = .55$. Both the percentage overlap, $F(2,60) = 12.31$, $MSE = 5508.69$, $p < .001$, $\eta_p^2 = .29$, and the distance deviation, $F(2,60) =$

21.67, $MSE = 40704.95$, $p < .001$, $\eta_p^2 = .42$, were affected by cue type in that the percentage overlap was lower and the distance deviation was higher when only distal cues were present on the map than when proximal cues were also present. The age $\times$ cue type interaction effect was not significant for percentage overlap, $F(2,60) = 2.01$, $MSE = 563.62$, $p = .14$, $\eta_p^2 = .06$, or distance deviation measures, $F(2,60) = .58$, $MSE = 701.28$, $p = .56$, $\eta_p^2 = .02$.

Younger adults were more confident that they identified the true location of the platform than were older adults, $F(1,61) = 48.75$, $MSE = 41799.49$, $p < .001$, $\eta_p^2 = .44$. Their distance deviation estimates were also shorter indicating that younger adults believed the distance between the true location of the platform and the selected location was closer than did older adults, $F(1,61) = 18.56$, $MSE = 10792.23$, $p < .001$, $\eta_p^2 = .23$. Participants CJs were lower when only distal cues were present than when proximal cues were present, $F(2,60) = 30.83$, $MSE = 11728.88$, $p < .001$, $\eta_p^2 = .51$. Distance deviation estimates were also larger when only distal cues were present than when proximal cues were present, $F(2,60) = 9.60$, $MSE = 2589.02$, $p < .001$, $\eta_p^2 = .24$. The age $\times$ cue interaction was not significant for CJs, $F(2,60) = 1.17$, $MSE = 386.18$, $p < .32$, $\eta_p^2 = .04$, or for distance deviation estimates, $F(2,60) = 1.17$, $MSE = 371.01$, $p = .32$, $\eta_p^2 = .$

Correlations between Spatial Performance Measures.

Table 3 shows the correlations between younger (top triangle) and older adults' (bottom triangle) performance on each spatial task. There was relatively high consistency between measures of visual spatial working memory, spatial orientation, and spatial visualization for both younger and older adults. These tasks were not significantly associated with performance for navigation and place learning. Fischer r to z tests indicated that the correlation between performance on the spatial span task and the paper folding test were higher for older adults than younger adults, $Z = 2.12$, $p < .05$. No other correlations were significantly different.

Absolute Accuracy of Metacognitive Judgments

Age differences in the absolute accuracy of metacognitive judgments were examined by computing the calibration component (which is sometimes referred to as reliability) of Murphy's (1973) decomposition of a brier score for each participant. Absolute accuracy refers to whether the average magnitude of an individual's judgments corresponds to their overall level of performance. Calibration scores near zero reflect perfect absolute accuracy with increasing values reflecting deviations from perfect accuracy. Calibration scores are presented in Table 4 for the spatial span task, 2d mental rotation, 3d mental rotation, and paper folding test. Table 4 shows that absolute accuracy was equivalent for younger and older adults in every spatial task.

To examine the absolute accuracy of navigation time estimates presented in Figure 3, we computed difference scores for predicted and actual time per trial for both younger ($M = -7.87$, $SE = 4.83$) and older adults ($M = -10.89$, $SE = 11.93$). Both age groups' estimates displayed overconfidence in that they significantly underestimated how long it would take to

navigate to the hidden platform, $t_s > 4.98$. However, the amount of underestimation did not differ as a function of age, $t(61) = 1.34$, $p = .19$, $d = .33$.

Correlations were computed between absolute accuracy scores on each spatial tests to evaluate intra-individual consistency in absolute accuracy across spatial domains. Table 5 presents the correlations separately for younger (top triangle) and older adults (bottom triangle). Table 5 reveals that poor calibration in the 2d mental rotation task was associated with poor calibration in every other spatial task for older adults. There was also a significant positive association between poor calibration in the 3d mental rotation task and the paper folding test. In contrast, the absolute accuracy for younger adults was far less consistent across spatial tasks than older adults. In fact, in most cases, correlations were near zero. Only the spatial orientation tasks were significantly correlated for younger adults which indicates that absolute accuracy for spatial orientation is stable across different measures of the same construct. Overall these results suggest that older adults are more likely to be over/under confident across multiple spatial domains whereas younger adults' absolute accuracy is more domain specific.

Relative Accuracy of Metacognitive Judgments

Gamma correlations (γ) were computed between metacognitive judgments and performance across trials for each individual to examine the relative accuracy of judgments which reflects item-level discrimination of correct and incorrect trials (for rationale, see Gonzalez & Nelson, 1996; Nelson, 1984)². Table 4 presents the mean relative accuracy (γ) for (1) JOLs and memory for spatial patterns in the spatial span task, (2) CJs and performance on the 2d mental rotation trials, (3) CJs and performance on 3d mental rotation trials, (4) CJs and performance on paper folding trials, and (5) between time estimates and actual time elapsed during navigation trials in the vMWM. Younger and older adults were equally accurate at discriminating between accurate and inaccurate trials in every spatial task except for the vMWM. Older adult's navigation estimates in the vMWM were not sensitive to the navigation time necessary to reach the platform on each trial. In contrast, younger adults were more accurate at discriminating between fast and slow navigation trials. These results suggest that monitoring spatial navigational performance may be prone to age related cognitive decline. However, Table 4 highlights that monitoring performance in other spatial tasks show age related sparing despite spatial processes themselves being impaired in later adulthood.

Given that the cognitive mapping tasks consisted of only 3 trials, gamma correlations could not be reliably computed for each individual to examine relative accuracy of distance confidence estimates. However, relative accuracy was examined using multilevel mixed effects modeling. These analyses are presented in the appendix for interested readers.

Table 6 shows the correlations between relative accuracy measures across spatial tasks for younger (upper triangle) and older adults (lower triangle). Only relative accuracy for the

²Given recent criticism about biased estimations with gamma under some conditions (Benjamin & Diaz, 2008; Mason & Rotello, 2009), we also examined relative accuracy using multilevel mixed effects modeling (for rationale, see Murayama, Sakaki, Yan, & Smith, 2014). There were no differences in our conclusions for any tasks when these analyses were used instead of gamma. Multilevel analyses are presented as supplemental materials for interested readers.

spatial span task and the paper folding test were significantly correlated for older adults. Relative accuracy correlations were not significant for any spatial task for younger adults. To summarize, there was little to no intraindividual consistency in the relative accuracy of metacognitive judgments across spatial domains for either age group.

Confidence in Spatial Memory and Navigation Strategy Preference

Results from the probe trial of the y-maze indicated that younger adults preferred using allocentric navigation strategies (61% allocentric and 39% egocentric) whereas older adults preferred using egocentric strategies (28% allocentric and 72% egocentric). These age differences in allocentric strategy preference were significant, $\chi^2(1) = 7.52, p < .05$, replicating previous findings from Rogers, Sindone, and Moffat (2012).

As mentioned above, older adults were also less confident in their place memory on the cognitive mapping task ($M = 52.93, SE = 5.45$) than were younger adults ($M = 73.70, SE = 3.20$). To examine whether these differences in confidence in memory for locations mediated the effects of age on strategy preference, we used Mackinnon and Dwyer's (1993) method for testing mediation with dichotomous outcomes. The mediation model is depicted in Figure 5. Age negatively predicted both confidence ($\beta = -.39$) and allocentric strategy preferences ($\beta = -.38$), whereas confidence positively predicted allocentric strategy preference ($\beta = .46$).

Tests of the indirect effect and the direct effect of age on strategy preference were examined using non parametric bootstrap estimation with 1000 samples. Bootstrap estimation allows for the computation of SE and confidence intervals (CIs) of the indirect, direct, and total effects and is preferred method of testing mediation effects when the nature of distributions for effects are unknown (as with metacognitive judgments, see Nelson 1984), nonnormal, or sample size is small (Bollen & Stine, 1990; Preacher & Hayes, 2004; Shrout & Bolger, 2002). Both percentile and biased corrected CIs were computed for each effect (for rationale, see Hayes & Scharkow, 2013) using STATA (StataCorp, 2013). Standard errors and CIs for each effect are depicted in Table 7. The indirect effect of age on strategy preference ($\beta = -.18$) was significant regardless of whether percentile CIs or bias corrected CIs are examined (CIs do not include zero). In contrast, the direct effect of age on strategy preference ($\beta = -.20$) was not significant (CIs include zero). Overall, confidence mediated 47% of the total effect of age on strategy preference.

Discussion

The current experiment evaluated age-related differences in performance and performance monitoring for visual spatial working memory, spatial orientation, spatial visualization, and spatial navigation. Across tasks, older adults displayed poorer performance and lower confidence in their spatial cognitive abilities but for most spatial domains there were no age differences in either the absolute or relative accuracy of metacognitive judgments. Our results also suggest that an exception to the sparing of monitoring of spatial cognition may be in the domain of navigation. These findings generally support the hypothesis that the metacognitive processes responsible for monitoring spatial cognition may be largely spared from the age-related decline that impacts spatial processing itself (for reviews of spatial

cognitive decline in older age, see Klencklen et al., 2012; Moffat, 2009). Despite the current findings and evidence of age-invariance of metacognitive monitoring accuracy in other domains (Backman & Karlsson, 1985; Butterfield, Nelson, & Peck, 1988; Hertzog & Dunlosky, 2011; Hertzog et al., 2002; Hertzog, Dunlosky, & Sinclair, 2010), the conclusion that monitoring processes are spared from age-related decline is equivocal (Crawford & Stankov, 1996; Perrotin et al. 2006; Souchay et al., 2000; Souchay et al., 2007). In fact, Thomas et al. (2012) provided evidence that monitoring spatial cognition may be compromised in later adulthood. Contrary to the current results, they observed age-related decreases in the relative accuracy for monitoring visual-spatial working memory. However, they used a more complex visual working memory task than the one used in the current experiment. Their task required binding unique items (e.g. different shapes) to different spatial locations whereas the visual spatial working memory task we used involved remembering locations of white squares. These methodological differences (remembering the location of multiple objects types vs. a single object type) could be key to understanding the discrepancies between these results.

A key distinction between spatial tasks concerns whether the task requires static versus dynamic processing. Static spatial tasks involve processing a single object and dynamic spatial tasks require processing multiple objects across time and space (Hunt, Pellegrino, Frick, Farr, & Alderton, 1988). Static spatial tasks include the mental rotation, paper folding, and even the visual spatial working memory task we used in the current experiment; all of which failed to produce age differences in monitoring accuracy. Dynamic spatial tasks include more complex spatial processing such as navigation. Interestingly, we observed age differences in relative accuracy for metacognitive judgments on the vMWM the only measure of dynamic spatial processing we administered. When one considers these results in the context of Thomas et al.'s findings, it suggests that older adults' performance monitoring could be compromised for dynamic spatial cognitive tasks but not for static spatial tasks. However, this conclusion should be interpreted cautiously without ruling out other hypotheses for why age differences occurred for monitoring navigation performance in the current experiment.

One hypothesis is that fatigue contributed to the age differences in monitoring that occurred for the navigation tasks because the navigation tasks occurred at the end of experiment. Limited research exists examining the effects of fatigue on metacognition, but the available evidence suggests that metacognitive monitoring accuracy may be resistant to fatigue effects even in extreme cases (Baranski, 2007). To date, no research has examined the effects of fatigue on metacognition for aging populations and it is possible that older adults' metacognitive processes are more susceptible to fatigue than younger adults. If so, the differences we observed in monitoring performance on the vMWM may not reflect a true age deficit in monitoring dynamic spatial processing.

Alternatively, procedural and cohort (e.g., experience and comfort with virtual tasks) differences could explain why age differences in relative accuracy occurred for only the spatial navigation task. One key procedural difference between the spatial navigation task and the standard psychometric measures of spatial ability we examined was the use of pre-decisional vs. post-decisional confidence procedures. Confidence judgments on the

psychometric tests were performed *after* item completion (post-decisional confidence) whereas confidence judgments for the navigation tasks were queried *before* participants completed a trial (pre-decisional confidence) because it would otherwise be obvious to them if they did or did not locate the goal location. This provided participants with some additional information in assessing trial-by-trial success on the psychometric measures that was not available to them for the navigation task. Specifically, people could base their confidence judgments on feedback from the experience of engaging in spatial processing for each trial (e.g. processing fluency, whether responses were guesses, etc.). Moreover, the navigation task required making time-based assessments. Presumably, all participants could eventually locate the platform (even if by chance) if given unlimited time. To address this and to derive a dichotomous (correct/incorrect) statistic for each trial, navigation trials were limited to 60s. These procedural constraints may have contributed to making metacognitive judgments inherently more difficult in the navigation task, a feature that might have negatively disadvantaged older adults. This is especially likely since older adults prefer to sample less information during pre-decisional information search than younger adults (Mata & Nunes, 2010).

Cohort differences could also explain why age differences occurred for only the navigation tasks. The spatial navigation tasks required navigating a virtual environment and virtual navigation is a less familiar task for older adults than younger adults. Although, we controlled for computer experience and ability, older adults' limited experience navigating in virtual environments may have made it more difficult for them to monitor and predict their navigation performance. However, one might expect that this unfamiliarity with a virtual navigation task would bias older adults toward underestimating their performance rather than overestimating how well they would perform as they did in the present study. Future research could address this issue by testing monitoring navigation performance in a real world navigation task or by providing more extensive training in the virtual environment for older adults.

The most consistent outcome we observed across multiple spatial constructs was that older adults could monitor their spatial performance as well as younger adults. Since, we examined many spatial constructs in a single experiment; one might expect to find some differences by chance alone. Thus, we urge readers to proceed cautiously in interpreting an age deficit in monitoring navigation performance without additional replications of this deficit that address the concerns raised above. What is clear from the current findings is that older adults can accurately monitor their performance on static spatial tasks as well as younger adults. These findings are consistent with findings from episodic and semantic memory domains that support the hypothesis that healthy aging coincides with preserved metacognitive monitoring abilities (Backman & Karlsson, 1985; Butterfield, Nelson, & Peck, 1988; Hertzog & Dunlosky, 2011; Hertzog et al., 2002; Hertzog, Sinclair, & Dunlosky, 2010).

Nevertheless, if the age differences we observed for the navigation task reflects age-related monitoring differences (rather than procedural differences), older adults' poorer monitoring performance during navigation could be attributed to a number of age-related cognitive/monitoring factors. Navigation is an inherently multimodal cognitive task that requires a

number of relatively unique cognitive processes for successful completion (Moffat et al., 2007). Theoretically, monitoring and forecasting navigation performance requires attending to multiple sources of information, all of which are potentially diagnostic of successful performance. Navigation requires to some degree working memory and attention, accurate memory for a goal location, navigation/searching strategy selection, accurate calculation of the distance between one's current location and the goal location, and accurate estimation of speed and direction of movement from visual motion (optic flow). Inaccurate performance monitoring could occur due to age related deficits in one or more of these processes.

Age-related differences in performance are well documented for both egocentric distance and speed estimation (Kirasic, Allan, & Haggerty, 1992; Sciath et al., 1987). Older adults as compared to younger adults underestimate speed and overestimate egocentric distance when driving (Sciath et al, 1987; Schiff, Oldak, & Shah, 1992), but are more accurate at judging egocentric distance when they and the to-be estimated objects are stationary (Bian & Anderson, 2013). The monitoring assessments in the current experiment occurred while in a stationary position at the beginning of each trial. Thus, older adults should have been able to accurately estimate the distance between their starting location and the goal location. Even so, errors in distance estimation could have occurred due to differences in memory for the goal location which was certainly poorer for older adults. Moreover, the vMWM is optimally solved when participants link multiple objects with the goal location using triangulation to estimate its distance and angle from objects in the arena. If older adults did not realize this and used simpler heuristics (e.g. to the left of the tree) they could easily become overconfident and perform more poorly than anticipated on a subsequent trial.

In episodic memory tasks, age differences in relative accuracy sometimes emerge when the quality of initial encoding is poor for older adults (Hertzog, Dunlosky, & Sinclair, 2010). When memory is impoverished during monitoring because of poor encoding or other reasons, people will not have access to highly diagnostic cues such as whether relevant recollective details can be remembered. As a result they may overvalue less diagnostic cues such as familiarity to monitor memory. Age differences in the quality of encoding the spatial layout of the task environment could have undermined monitoring navigation and place learning in the current experiment and caused older adults to rely on less diagnostic cues than accessibility to infer their performance. One cue is previous success in navigating to the goal location. In memory tasks, younger and older adults typically use their memory for prior successful recall as a cue to infer later memory performance (Ariel & Dunlosky, 2011, Finn & Metcalfe, 2008; Serra & Ariel, 2014; Tauber & Rhodes, 2012). It is possible that older adults overvalued previous navigation success when estimating their navigation times on each trial in a similar manner. To evaluate this hypothesis, we computed gamma correlations between older adults' time estimates and their navigation success on the previous trial. Consistent with this hypothesis, a strong negative relationship was present indicating that older adults decreased their estimates following a successful navigation trial and increased time estimates following unsuccessful trials, (Mean $\gamma = -.86$, $SE = .06$).

In summary, there are several reasons to suspect that monitoring dynamic spatial cognitive processes like navigation could be compromised in older age despite age-equivalence in monitoring performance in static spatial domains. Dynamic spatial processing requires

monitoring continuous performance over time and space which may be more likely to reveal accuracy differences than static spatial tasks which require monitoring the outcome of a discrete choice (see Yeung & Summerfield, 2012). Future research is necessary to replicate and extend the current findings to determine both the robustness of these age differences and to competitively evaluate potential causal mechanism for them.

How do People Monitor Spatial Cognition?

The current experiment focused primarily on whether monitoring spatial cognition is resistant to the age related cognitive decline that occurs for spatial cognition itself. Given the limited research on monitoring spatial cognitive processes, a number of important questions remain. First, the processes utilized to monitor spatial cognition are not well understood. The general consensus is that monitoring in verbal/conceptual domains is a cue-driven heuristic process. However, some controversy exists regarding whether monitoring sensory or perceptual decisions (e.g., weight discrimination, line length, auditory discrimination, etc.) are also heuristic in nature or involve directly accessing the underlying psychological states being monitored (Bjorkan, Juslin, & Winman, 1993; Juslin & Olsson, 1997; Kvidera & Koutstall, 2008; Stankov, 1998). Intuitively, spatial cognitive processes seem more similar to sensory perceptual processes than verbal processes which raises the question, does monitoring spatial cognition involve direct or indirect (heuristic-based) access to the underlying cognitive states in question?

If monitoring spatial cognition was based on direct access, one might expect a greater correspondence between absolute accuracy and relative accuracy measures than we observed in the current experiments (Tables 5 and 6) because actual performance on many tasks were highly correlated (Table 3). Consider the high positive correlations between visual spatial working memory, spatial orientation, and spatial visualization performance measures in Table 3. If people have direct access to these processes when monitoring performance, monitoring accuracy should be systematically related across each spatial domain due to the overlap in processing involved in each task. However, this was not the case for all tasks; especially for younger adults. A heuristic-based account of monitoring could explain the intra-individual differences in monitoring accuracy in Tables 5 and 6. Presumably differences in monitoring could arise because people attend to different cues in different spatial tasks or because similar cues across spatial tasks differ in their diagnosticity (Dunlosky & Tauber, 2014).

Assuming that monitoring spatial cognition is a heuristic process, a second question concerns understanding what cues people use to infer the quality of their spatial processing. Possible cues that people could use to monitor visual spatial working memory, spatial orientation, and spatial visualization abilities include the fluency for generating and manipulating visual-spatial representations, as well as the perceived vividness of these representations (Pearson, Rademaker, & Tong, 2011). The effects of fluency on monitoring judgments were indirectly evaluated in the current experiments by computing gamma correlations between response times for trials of each spatial task and participants' metacognitive judgments. The results were consistent with the hypothesis that processing fluency is a cue that people use to monitor their spatial performance. People's metacognitive

judgments were more sensitive to processing fluency in some tasks than in others (paper folding > mental rotation > spatial span task) and in some cases this relationship was quite small (e.g., spatial span task). Thus, people likely attended to other cues as well to make their metacognitive judgments which again could explain the intra-individual differences in monitoring accuracy we observed across tasks (see Tables 5 and 6). What cues do people use to monitor navigation performance? The high gamma correlation between previous navigation success and time estimates in the current experiment suggest that familiarity with the goal location is a likely cue used to make metacognitive judgments about future navigation success. However, people may also base their judgments on recollective cues such as the amount of route information (directions, landmarks, etc.) they can recall when monitoring performance. The current experiments were not designed to examine the cues people use to monitor spatial cognition or even if younger and older adults attend to different cues when monitoring spatial processes. Thus, future research is necessary to understand the mechanism contributing to the accuracy of metacognitive monitoring in spatial domains.

Implications and Conclusions

Many everyday tasks utilize spatial cognitive processes. Whether one is trying to read a map, navigate the screen on their cell phones, or even understand scientific concepts, they may draw on spatial process to successfully perform these tasks. Low confidence could lead to unnecessary restriction of activities in these and other tasks that utilize spatial processes. For example, older adults might avoid using smart phones which contain useful applications for monitoring health outcomes because they perceive navigating the spatial displays on these devices is too difficult. Likewise, low confidence in spatial reasoning ability may cause younger adults to avoid course work or even careers in STEM domains that require spatial thinking.

Consider a potential chemistry major who is tasked with solving stereochemistry problems in an introductory course. This student is asked to identify whether a molecule is chiral or not. (i.e., can it be superimposed onto its mirror image?). Identifying chirality requires the student to visualize the mirror image of the object and to mentally rotate it to determine whether it aligns with the original molecule. If this student perceives their mental rotation ability as poor, they may find these and other stereochemistry problems frustrating which could affect decisions about pursuing future chemistry course work. If so, interventions that target confidence in spatial abilities could have implications for promoting STEM interest and retention.

The current experiment evaluated the implications of low spatial confidence on navigation strategies. Results indicated that typical age differences in preference for using allocentric vs. egocentric strategies were mediated in part by *confidence*. Low confidence in memory can cause older adults to avoid using memory-based strategies even when they have acquired the appropriate memory representations to quickly and accurately perform tasks via direct retrieval (Hines, Hertzog, & Touron, 2012; Touron & Hertzog, 2009). Older adults' navigation strategy preferences mirror this reluctance to use memory-based strategies and could be caused by either general underconfidence or even accurate perceptions that one's allocentric spatial processing is poor.

In summary, monitoring spatial cognition appears to be spared from age-related cognitive decline for at least static spatial domains. Overall, older adults are less confident in their spatial cognitive abilities than younger adults which has implications for the navigation strategies they adopt. However, future research is necessary to understand other implications of this low confidence, whether the age differences we observed in monitoring navigation performance reflect a true age-related deficit, and to better understand how younger and older adults monitor their spatial cognitive processes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Illustration of the virtual y-maze task. Participants can move forward and proceed down either the left or right hallway to find the goal location. When participants find the goal location located at the end of the left hallway, a pleasant tone is triggered.

Figure 2.

Illustration of the virtual Morris water maze which involves navigating from random starting locations to find a stationary hidden platform in the pool. The starting location for a typical trial is illustrated in the left panel above and an overhead map of the pool depicting cues in the room is presented in the right panel. This overhead map is the same map used for the both cues condition of the cognitive mapping task where participants were asked to click the location in the pool where they believe the platform was located.

Figure 3.

Mean percentage for JOLs and recall accuracy in the spatial span task as a function of the memory load condition for younger and older adults. Results show that memory performance and confidence are higher for younger than older adults and both variables decrease as memory load increases.

Figure 4.

Mean time estimation and mean actual time for locating the platform on each trial of the Morris Water Maze for younger and older adults. Both younger and older adults' were overconfident for their predicted navigation times in that they consistently underestimated the amount of time it would take to navigate to the platform.

Figure 5.

Confidence in memory for platform location as a mediator of the effects of age on allocentric strategy preference. * denotes $p < .05$.

Table 1.

Mean performance accuracy, confidence judgments (CJs), and global CJs for the spatial orientation (2d and 3d mental rotation) and spatial visualization (paper folding) tests and corresponding independent sample t-test.

	Younger Adults	Older Adults	<i>t</i>	df	<i>p</i>	<i>d</i>
2d mental rotation						
Accuracy	90.29 (2.15)	73.73 (4.69)	3.24	67	<.008	.78
CJs	80.54 (2.53)	72.61 (3.56)	1.82	67	.07	.44
Global CJs	81.86 (2.92)	66.09 (4.47)	2.97	67	<.008	.71
3d mental rotation						
Accuracy	75.98 (3.77)	58.77 (4.56)	3.32	67	<.008	.75
CJs	75.61 (2.98)	59.10 (4.55)	3.03	67	<.008	.79
Global CJs	71.68 (3.78)	54.36 (5.18)	3.32	67	<.008	.70
Paper folding test						
Accuracy	72.01 (1.48)	50.74 (2.87)	6.65	67	<.001	1.59
CJs	78.19 (2.55)	56.34 (3.85)	4.76	67	<.001	1.14
Global CJ	77.01 (2.76)	54.36 (4.83)	6.14	67	<.001	1.47

Note. Standard errors of the means are in parenthesis. Bonferroni corrected alphas of $p < .008$ were used for rejecting the null hypothesis for all analyses.

Table 2.

Mean memory performance and confidence judgments for the cognitive mapping test following the virtual Morris Water Maze for trials when only distal cues are present, only proximal cues are present, or both cues are present.

	Younger Adults			Older Adults		
	Distal Cues	Proximal Cues	Both Cues	Distal Cues	Proximal Cues	Both Cues
Percentage overlap	14.63 (3.44)	32.05 (4.65)	37.07 (4.57)	0.10 (.00)	5.69 (2.36)	14.69 (.05)
CJ	55.52 (4.33)	81.73 (2.30)	84.12 (1.92)	31.10(4.67)	47.53 (4.37)	53.40 (4.84)
Distance deviation	63.30 (7.66)	25.64 (2.33)	23.58 (2.34)	121.51 (6.91)	76.54 (8.02)	68.44 (8.56)
Distance Estimate	27.06 (2.54)	13.64 (2.55)	10.88 (2.06)	37.27 (4.10)	28.90 (3.56)	30.80 (4.80)

Note. Percentage overlap = percentage overlap of selected platform location and the true platform location. CJ = confidence judgment of one's accuracy for identifying the correct platform location. Distance deviation = distance deviation in pixels between the center of the selected platform location and the center of the true platform location. Distance estimate = the predicted distance between true location of the platform and the selected location. Distance estimates are in arbitrary units with higher values indicating farther distance. Standard errors of the means are in parenthesis.

Table 3.

Correlations between spatial performance measures for younger (upper triangle) and older adults (lower triangle).

	Spatial Span Task	2d Mental Rotation	3d Mental Rotation	Paper Folding Task	Cognitive Map	Morris Water Maze
Spatial Span Task	—	.23	.39	.22	-.01	-.32
2d Mental Rotation	.61	—	.78	.70	.29	-.26
3d Mental Rotation	.64	.76	—	.59	.11	-.04
Paper Folding Task	.64	.66	.67	—	.13	-.21
Cognitive Map	-.01	.24	.06	.29	—	-.09
Morris Water Maze	-.28	-.31	-.37	-.14	-.11	—

Note. Bolded values reflect correlations at $p < .05$.

Table 4.

Mean absolute accuracy computed as the calibration component of the brier score and mean relative accuracy (gamma correlations) for younger and older adults in each spatial task and corresponding independent sample t-test.

	Younger Adults	Older Adults	<i>t</i>	<i>df</i>	<i>p</i>	<i>d</i>
Absolute Accuracy						
Spatial span task	.08 (.01)	.13 (.02)	2.51	56	.05	.60
2d mental rotation	.06 (.01)	.08 (.02)	1.68	56	.10	.29
3d mental rotation	.09 (.01)	.11 (.02)	1.12	60	.26	.28
Paper folding	.09 (.01)	.11 (.02)	1.21	67	.23	.29
Relative Accuracy						
Spatial span task	.49 (.04)	.57 (.04)	1.18	67	.24	.28
2d mental rotation	.26 (.10)	.28 (.08)	.19	67	.84	.05
3d mental rotation	.27 (.08)	.27 (.07)	.04	60	.97	.01
Paper folding	.40 (.05)	.44 (.07)	.48	67	.89	.11
Morris water maze	.36 (.07)	-.04 (.06)	4.04	61	<.001	1.02

Note. Standard errors of the means are in parenthesis. Absolute accuracy reflects the calibration component (also known as reliability) of Murphy's (1973) decomposition of the brier score computed for each participant. Gamma correlations were also computed for each participant and means reflect means across individual's values. Bonferroni corrected alpha of $p < .008$ were used for rejecting the null hypothesis for all analyses.

Table 5. Correlations between absolute accuracy measures for younger (upper triangle) and older adults (lower triangle).

	Spatial Span Task	2d Mental Rotation	3d Mental Rotation	Paper Folding Task	Morris Water Maze
Spatial Span Task	—	.07	-.01	-.17	.11
2d Mental Rotation	.16	—	.50	-.01	.22
3d Mental Rotation	.26	.69	—	-.05	.04
Paper Folding Task	.32	.75	.60	—	.08
Morris Water Maze	-.18	-.66	-.31	-.30	—

Note. Bolded values reflect correlations at $p < .05$. Absolute accuracy was computed using the calibration component of Murphy's decomposition of the Briar score in all tasks except for the Morris water maze. Absolute accuracy in the Morris water maze reflects differences between predicted navigation time and actual navigation time, and hence, negative values are possible for this measure.

Table 6.

Correlations between relative accuracy for younger (upper triangle) and older adults (lower triangle).

	Spatial Span Task	2d Mental Rotation	3d Mental Rotation	Paper Folding Task	Morris Water Maze
Spatial Span Task	—	.15	.10	.07	.14
2d Mental Rotation	-.26	—	.25	-.03	-.34
3d Mental Rotation	-.21	.13	—	-.24	-.06
Paper Folding Task	.58	-.28	-.13	—	.03
Morris Water Maze	.15	-.10	.26	.18	—

Note. Bolded values reflect correlations at $p < .05$. Relative accuracy measures were computed using gamma correlations.

Table 7.

Mediation of the effect of age on allocentric strategy preference through confidence in location memory during the cognitive mapping test.

Fixed Effects	β	SE	Percentile 95% CI		Bias Corrected 95% CI	
			Lower	Upper	Lower	Upper
Mediation model						
Indirect Effect	-.18	.07	-.34	-.06	-.34	-.06
Direct Effect	-.20	.13	-.45	.08	-.45	.08
Total Effect	-.38	.12	-.61	-.12	-.59	-.10

Note. SE = Standard Error. CI = confidence intervals. SEs and CIs were computed using non parametric bootstrap estimation of effects with 1000 samples.