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Age-related differences in the use of spatial and categorical relationships in a visuo-spatial working memory task

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Abstract
Research examining object identity and location processing in visuo-spatial working memory (VSWM) has yielded inconsistent results on whether age differences exist in VSWM. The present study investigated whether these inconsistencies may stem from age-related differences in VSWM sub-processes, and whether processing of component VSWM information can be facilitated. In two experiments, younger and older adults studied 5 × 5 grids containing five objects in separate locations. In a continuous recognition paradigm, participants were tested on memory for object identity, location, or identity and location information combined. Spatial and categorical relationships were manipulated within grids to provide trial-level facilitation. In Experiment 1, randomizing trial types (location, identity, combination) assured that participants could not predict the information that would be queried. In Experiment 2, blocking trials by type encouraged strategic processing. Thus, we manipulated the nature of the task through object categorical relationship and spatial organization, and trial blocking. Our findings support age-related declines in VSWM. Additionally, grid organizations (categorical and spatial relationships), and trial blocking differentially affected younger and older adults. Younger adults used spatial organizations more effectively whereas older adults demonstrated an association bias. Our finding also suggests that older adults may be less efficient than younger adults in strategically engaging information processing.

Keywords Working memory · Aging

Introduction

Remembering where an object is located in the world, or visuo-spatial working memory (VSWM), requires one to remember what they are looking for and where it is. Studies examining how our ability to remember object identity and location changes with age has consistently demonstrated that older and younger adults may differ in VSWM processing. The literature has been predominantly concerned with understanding binding deficits in VSWM. However, the prevailing theory suggests that component information (e.g., object identity or spatial location) are processed independently and then bound (for review see Logie, 1995). The present research focused instead on age-related differences in component processing to better understand the nature of commonly found age differences in VSWM. Research suggests that as we age, the way information is processed shifts. For example, as young adults we tend to rely on spatial relationships more so than categorical relationships (Thomas, Bonura, & Taylor, 2012a). The present research also investigated the influence of this age-related shift in processing within the context of a VSWM task.

VSWM, according to Baddeley and Hitch (1974), is a subsystem of working memory that deals with visuo-spatial information. Research suggests that within VSWM, location and object identity processing may be dissociated (Köhler, Moscovitch, & Melo, 2001; Logie & Marchetti, 1991; McCarthy, Puce, Constable, Krystal, Gore, & Goldman-Rakic, 1996). For example, Logie and Marchetti (1991), in a divided attention task, found that concurrent spatial tapping disrupted memory for locations, whereas learning line drawings impacted memory for color shades. Similarly, Köhler et al. (2001) found that judging spatial relationships during encoding selectively improved object location memory, whereas judging physical information and naming the objects during encoding preferentially benefited object identity memory.

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Other evidence supporting the dissociation of location and object identity processing comes from findings that these two types of processing may have asymmetric cognitive resource demands (Hasher & Zacks, 1979; Huang, Treisman, & Pashler, 2007; Johnston & Pashler, 1990; Thomas, Bonura, Taylor, & Brunyé, 2012b). Researchers have argued that location processing may be automatic, or at least less effortful than identity processing (Huang et al., 2007; Johnston & Pashler, 1990; Mandler, Seegmiller, & Day, 1977; Pezdek, 1983; Taylor, Thomas, Artuso, & Eastman, 2014; Thomas et al., 2012b). For example, Mandler et al. (1977) found that participants processed spatial locations even without instructions to do so. Further, Huang et al. (2007) showed that participants encoded only one object feature at a time, but multiple spatial locations simultaneously. Finally, cognitive load, as operationalized through object array size, only minimally influenced location memory, but negatively affected object identity and combined identity-location memory (Thomas et al., 2012b).

Considering that location and object identity processing are dissociative VSWM components, research has examined whether age differentially affects them. However, previous findings seem to be mixed. Some findings suggest that location processing does not vary between younger and older adults (Ellis, Katz, & Williams, 1987; Mandler et al., 1977). Other studies observed age-related deficits in location memory, such that younger adults out-performed older adults in a variety of visuo-spatial memory tasks (Brockmole & Logie, 2013; Light & Zelinski, 1983; Meneghetti, Fiore, Borella, & De Beni, 2011). When comparing location and identity processing, studies found that spatial processing may decline with age, while object identity processing may not (Chalfonte & Johnson, 1996; Jenkins, Myerson, Joerding, & Hale, 2000; Wilkniss, Jones, Korol, Gold, & Manning, 1997). As one example, Chalfonte and Johnson (1996) examined younger and older adults' memory for objects displayed within arrays. They found age-related deficits in location memory, but age-invariance associated with object identity memory (Chalfonte & Johnson, 1996). Other findings suggest age-related deficits in both location and identity processing. Thomas and colleagues (2012a, b), for instance, found that older adults demonstrated age-related deficits in location, object identity, and combined identity-location memory. When older adults had additional study time, however, age differences on identity and location memory disappeared, but identity-location binding deficits remained (Thomas et al., 2012b).

Taken together, although previous research has not agreed on whether VSWM declines with age, younger and older adults may differ in how they approach VSWM tasks (Chalfonte & Johnson, 1996; Thomas et al., 2012b). The present study aims at further exploring age-related VSWM processing, and whether structuring the stimuli and/or the task differentially impacts younger and older adults. In order to investigate these questions, it is important that we address possible influences on VSWM.

Several factors may positively influence visuo-spatial information processing. First, global patterns, either spatial or categorical relationships, may facilitate processing. According to Navon's *global precedence hypothesis* (1977), participants process global information earlier than local information, resulting in faster responses to global features than to local details of the stimuli. Taylor et al. (2014) also observed this global pattern advantage. They had college students study 5 × 5 grids containing five objects, and found that organizing objects into recognizable configurations improved location memory. Similarly, semantic categories, as global semantic patterns, may improve object identity memory, suggesting a categorical "global precedence." For example, semantically meaningful relationships facilitated memory for object identities (Maddox, Rapp, Brion, & Taylor, 2008; Merrill & Baird, 1987; Thomas et al., 2012a). Merrill and Baird (1987) found that people used category hierarchies to improve map memory. Thomas et al. (2012a) showed better landmark memory when maps were organized by semantic categories. Therefore, global relationships, either spatial or categorical, may facilitate visuo-spatial memory.

Previous studies have also suggested that spatial and categorical relationships may affect younger and older adults differently. For example, compared with older adults, younger adults may be more likely to spatially organize map information during learning, resulting in better memory for the relative landmark location (Thomas et al., 2012a). In contrast, older adults may more likely rely on categorical relationships. Verbal learning research demonstrates that older adults use semantic-based strategies to support recall (Fernandes & Grady, 2008), and may even be biased by semantic categorical relationships (Thomas & Sommers, 2005; Tun, Wingfield, Rosen, & Blanchard, 1998). Taken together, these findings suggest that providing spatial and/or categorical relationships may differentially influence younger and older adults' VSWM processing.

The second factor—strategic processing—usually introduced via explicit instructions or changing the task structure, affects information processing depth and improves both episodic long-term memory (Craik & Lockhart, 1972; Gross & Rebok, 2011), and short-term visuo-spatial memory (Light & Zelinski, 1983; Pezdek & Evans, 1979). As one example, Pezdek and Evans (1979) gave younger participants instructions that encouraged either identity or location processing, and found enhanced recognition of information related to the encouraged process (see also Thomas et al. 2012a). Thus, encouraging strategic processing could facilitate participants' memory for visuo-spatial information in a VSWM paradigm.

In sum, global relationships (spatial and/or categorical) and strategic processing may facilitate older and younger adult attribute processing (location and/or object identity) in VSWM tasks. In the present study, we manipulated spatial and categorical relationships between studied objects in each trial to provide trial-level facilitations, and blocked trials by question types (Experiment 2) to encourage strategic processing at the task level, to explore whether we can promote VSWM processing for younger and older adults.

The present study

The present work includes two experiments. Experiment 1 explored whether trial-level manipulations, including spatial organizations and/or categorical associations in each trial, would facilitate location and object identity processing in younger and older adults. To encourage strategic processing, Experiment 2 blocked trials by recognition question type, such that participants knew, during each block, what information would be tested: location only, identity only, or the combination of the two. According to previous literature, age-related differences were predicted, especially on more complex combination questions (Thomas et al., 2012b). We also predicted that both younger and older adults should benefit from our trial-level (grid organizations) and task-level (task-blocking) manipulations, but the levels of facilitation should differ by age. Based on previous findings (Fernandes & Grady, 2008; Thomas & Sommers, 2005; Thomas et al., 2012a), spatial organization should have a greater impact on younger adult performance, while object association by category should have a greater influence on older adults. Block-level facilitation was implemented to indirectly encourage strategic processing. We expected that both older and younger adults would improve with trials blocked by question type; however, blocking may differentially impact these two age groups. Although blocking was implemented to highlight what participants should attend to and process, participants were not given explicit instructions to attend to the task structure. As such, younger adults may show a greater benefit of blocking as compared to older adults (cf., Thomas et al., 2012a; Thomas & Millar, 2012).

Experiment 1

In Experiment 1, we manipulated spatial and categorical relationships within grids to improve individual VSWM component processing. We hypothesized that spatial organization should facilitate location memory whereas category association should improve object identity memory. Further, consistent with previous literature, spatial organization and category association were hypothesized to differentially impact older and younger adults. Young adults have been shown to rely more on spatial organization than category relationships in VSWM tasks (Thomas et al., 2012a). As such, we expected that spatial organization would have a greater impact on younger adults. Alternatively, category association has been shown to have a greater impact on older adult memory (Fernandes & Grady, 2008; Thomas & Sommers, 2005; Tun et al., 1998). As such, within grid categorical relationships were expected to have a greater impact on older as compared to younger adult performance. In addition, age-related deficits were expected, especially on more resource-demanding questions targeting combined location and object identity information.

Methods

Participants A statistical power analysis (G*Power 3.1; Faul, Erdfelder, Lang, & Buchner, 2007) was performed for sample size estimation. The results indicated a sample size of 64 in Experiment 1 would be sufficient to detect effects of manipulations, with a power of .80, an effect size of .25, and an alpha of .05.

A total of 64 participants, including 32 younger adults (16 female and 16 male) and 32 older adults (22 female and 10 male), participated in Experiment 1. Younger adults were Tufts University undergraduates (aged 17–23 years, M = 18.72, SD = 1.11; education M = 13.64 years, SD = 1.37; Shipley vocabulary test M = 13.19, SD = 1.69) and received course credit for their participation. Older adults (aged 60–84 years, M = 67.68, SD = 5.84; education M = 16.69 years, SD = 2.57; MMSE M = 29.09, SD = 1.06; Shipley vocabulary test M = 14.78, SD = 2.21) were community dwelling older adults, recruited from an older-participants pool maintained by the Cognitive Aging and Memory Lab, and were paid US$15 per hour for participation.

Design This experiment used a 2 (Spatial Organization: *Organized, Unorganized*) × 2 (Category Association: *Associated, Unassociated*) × 3 (Question Type: *Location, Object, Combination*) × 2 (Group: *Younger, Older*) mixed design, with Spatial Organization, Category Association, and Question Type as the within-subject variables, and Group as the between-subject variable.

Materials

Items. The object pictures involved color line drawings, adapted from Rossion and Pourtois (2004), and were separated into 18 different categories following Battig and Montague's (1969) category norms. Additional objects were selected from Clker (http://www.clker.com) to match Rossion and Pourtois' pictures on color and texture. Because stimuli were drawn from two separate sources, we collected normative data from a separate group of 20 participants on naming agreement, response latencies, and picture similarity. Based on the normative data, images from Clker did not differ significantly from Rossion and Pourtois' images. See Fig. 1 for sample items and study grids.

Grids. To-be-studied stimuli included 144 grids of 5 × 5 each containing five objects displayed in different locations. Each grid was approximately 15 cm × 15 cm in size, with 2.5 cm × 2.5 cm objects placed at the center of 3 cm × 3 cm small cells. These five objects could be associated by category (all five associated with the same category) or unassociated with each other (all five from different categories). For 72 grids, items were spatially organized (i.e., forming recognizable configurations such as a vertical or horizontal line, L, b, V, T or a cross, see Fig. 1 for an example). For the other 72 grids, items were randomly placed (i.e., with no obvious spatial pattern between objects, see Fig. 1). Individual locations and items were relatively equally distributed across grids.

Questions. Recognition questions were constructed so that 25 % of trials contained correct identity, location, or combination information. The remaining 75 % were incorrect lures. This ratio was generated based on previous studies conducted in the lab (e.g., Thomas et al., 2012a, b). The ratio also affords an opportunity to conduct analyses of false alarms. However, as the examination of false alarm responding is not the focus of the present manuscript, these analyses are not reported in detail.

Among the 144 recognition trials, 32 tested location, 32 tested identity, and 80 tested combined identity and location information. For location tests, participants were asked, "*Was an object presented in this location in the previous grid?*" The question was paired with an objectless grid with a single square highlighted in red. The highlighted section was either a previous-occupied cell (correct) or a previous-unoccupied cell (incorrect lure). Identity trials asked "*Was this object presented in the previous grid*?" and were presented with an object, without the grid context, that was either previously studied (correct) or unstudied (incorrect). When both location and identity were tested in combination, participants saw a grid containing an object (either studied or unstudied) in a cell (either previously occupied or unoccupied) and were asked, "*Was this object presented in this location in the previous grid?*" Participants were instructed to press the *yes* ("a") or *no* ("k") key for all responses. Study-test trials were counterbalanced to ensure that each of the studied grids appeared with at least two different question types across the three counterbalances.

Lures differed by question type. Location trials only had one lure type (a cell that had not been occupied in the studied grid). Object identity trials had two lure types, an unstudied object was either categorically related or unrelated to a studied object. Specifically, when the five studied objects came from the same category, the lure could be from that category (related lure) or from a different category (unrelated lure). When the studied objects were from different categories, the lure could relate to one of the objects (related lure), or be completely unrelated to any of the studied objects (unrelated lure). Combined identity and location trials included five lure types, crossing the location and object lure types. An object (either studied, new unrelated, or new related) could appear in a new location, or an object lure (new related or new unrelated) could appear in a studied location. Examples of lures can be found in Fig. 2. On combination trials, new objects were classified as those not studied on a given grid. New locations were classified as those not occupied on the studied grid.

Verbal test and questionnaires. Both younger and older participants completed a general vocabulary test (Shipley, 1946) before the VSWM task. Older adults also completed a Mini-Mental Status Exam (MMSE; Folstein, Folstein, & McHugh, 1975).

Procedure All procedures were approved by the Social, Educational and Behavioral Research (SBER) IRB at Tufts University. Stimuli were presented on a standard personal computer monitor via E-prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2001). Participants were instructed to sit at a distance of 50 cm away from the computer monitor. They first gave informed consent. Following this, participants completed the Shipley vocabulary test, followed by a practice session that familiarized them with the continuous recognition paradigm where yes/no decisions were made on each trial, employed in the experiment. In the practice phase, participants did two trials for each question type. Before practice and again before the experimental trials, participants received instruction that they would "*be presented with a series of displays containing various objects in various locations within a grid.*" Each grid appeared at the center of the computer screen for 3 s.

After studying a given grid, participants were asked, "*How likely are you to recognize the information shown in the grid?*" Participants responded using a Likert scale of 1–10 (with 1 being "*not likely at all to recognize*" and 10 being "*extremely likely to recognize*"). These judgments of learning (JOL) were collected for consistency with previous research (e.g., Thomas et al., 2012b), but are not included in the present study. Following the JOL question, participants made a yes/no recognition decision for the previous trial. The order of trials was randomized in Experiment 1.

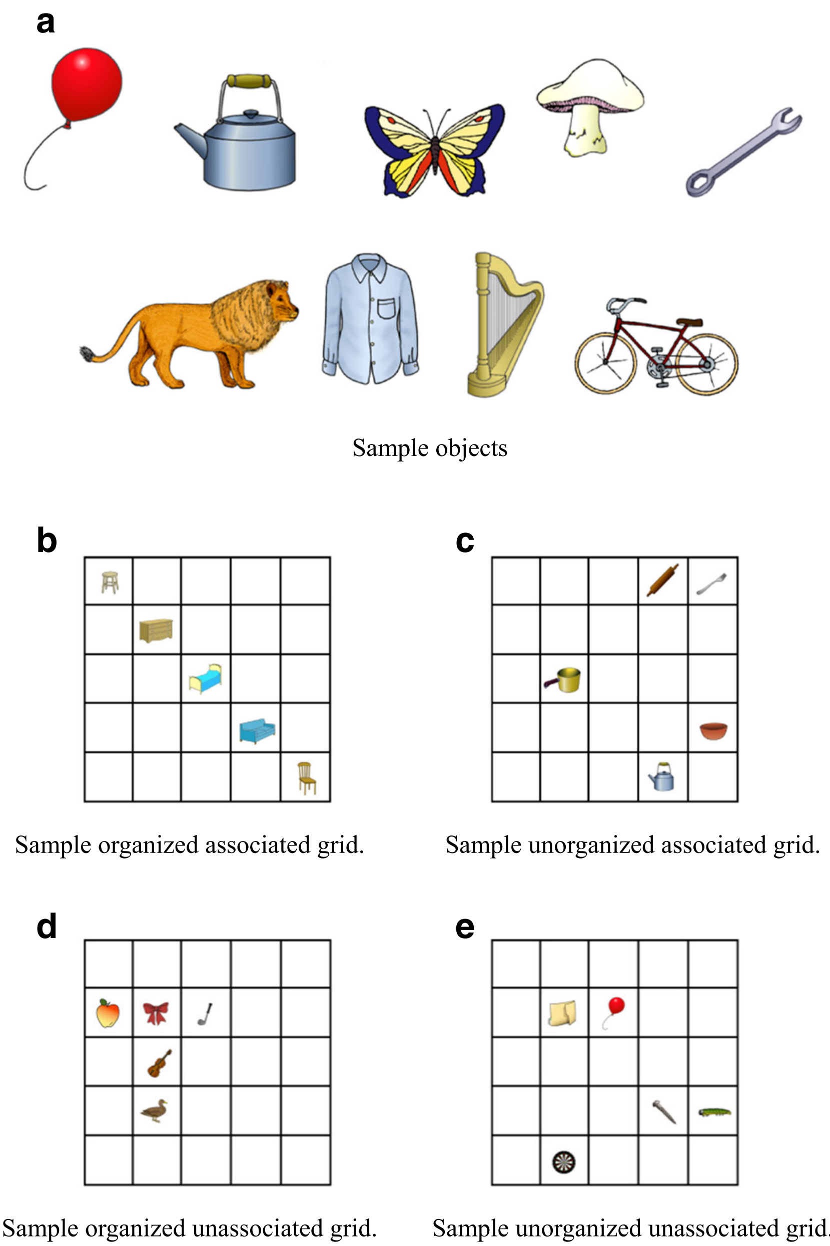


Fig. 1 Sample stimuli. **a**. Sample objects. **b**. Sample organized associated grid. **c**. Sample unorganized associated grid. **d**. Sample organized unassociated grid. **e**. Sample unorganized unassociated grid

After all trials, participants completed a demographic questionnaire. Older adults also completed the MMSE. All participants received a debriefing form and were thanked for their participation.

Results

Memory performance was evaluated by examining participants' ability to distinguish studied information from lure information. In the present study, we looked at d′ values, false alarm rates, and βs for location, object identity, and combination questions, separately. When computing d′ and β values, participants' false alarm rates were collapsed across different lure types. Preliminary analysis on mean false alarm responses and β values showed that older and younger adults demonstrated similar patterns of false alarms and βs for the different lure types associated with object-identity and combination trials. Therefore, for simplicity, we present analyses of false alarms and β values collapsed across lure types. Analyses used 2 (Spatial Organization: *Organized, Unorganized*) × 2 (Category Association: *Associated, Unassociated*) × 2 (Group: *Younger, Older*) mixed design ANOVAs on d′, false alarms and β values.

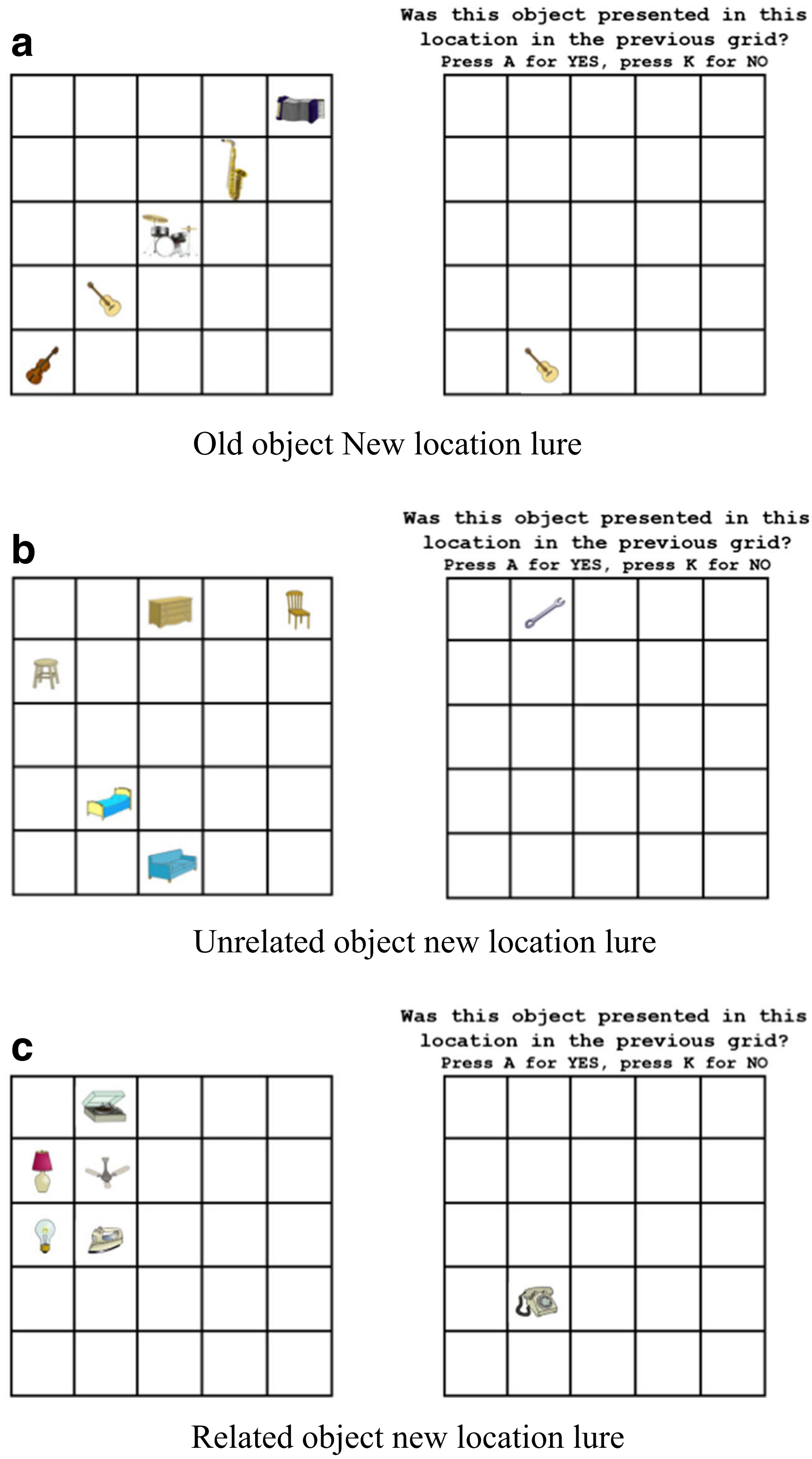
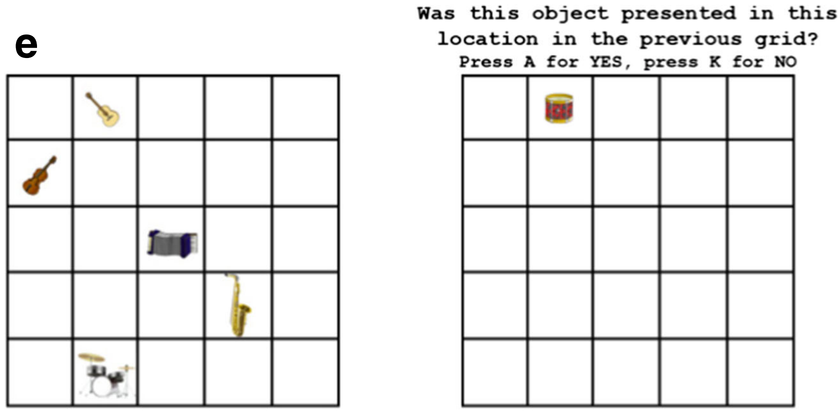


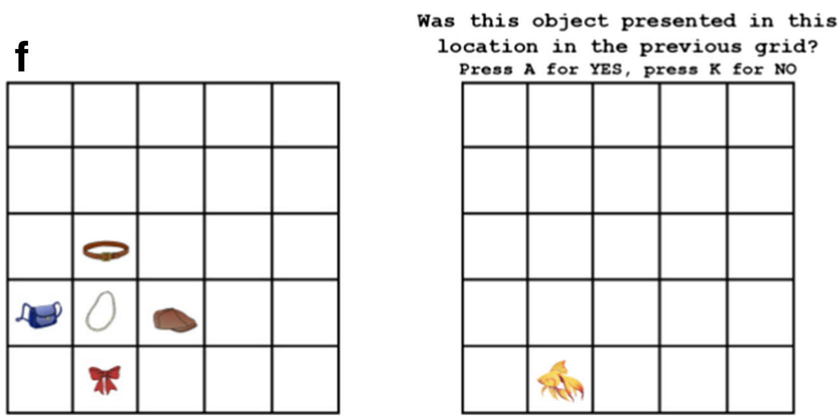
Fig. 2 Sample combination lures. **a**. Old object New location lure. **b**. Unrelated object new location lure. **c**. Related object new location lure. **d**. Related object old location lure. **e**. Unrelated object old location lure

Location memory Location trial d′ scores showed a main effect of Spatial Organization, $F(1, 62) = 59.93$, $p < .001$, $\eta_p^2 = .49$. Compared with unorganized grids ($M = 1.44$), participants demonstrated better location memory with organized grids ($M = 3.37$). No other main effects or interactions were found.

False alarm rates showed a main effect of Spatial Organization, $F(1, 62) = 15.48$, $p < .001$, $\eta_p^2 = .20$, wherein organization reduced location trial false alarms (Means: Organized = .11, Unorganized = .17). A main effect of Category Association was also found, $F(1, 62) = 6.75$, $p =$



Related object old location lure



Unrelated object old location lure

Fig. 2 (continued)

.012, η_p^2 = .10. Participants made fewer false alarms when grid objects were associated by category (*M* = .12) than unassociated (*M* = .17). Additionally, we observed an interaction between Category Association and Group, *F*(1, 62) = 4.81, *p* = .032, η_p^2 = .07. Using a Bonferroni corrected alpha value of .025, we found that categorical relationships did not affect older adults' location false alarms (Means: Associated = .14, Unassociated = .14, *t* < 1), but reduced younger adults' false alarms on location trials (Means: Associated = .10, Unassociated = .19), *t*(31) = 3.34, *p* = .002, *d* = .67).

Analyses on location β values found no significant main effect or interaction.

Object identity memory Mean d′ scores yielded a main effect of Category Association, *F*(1, 62) = 15.50, *p* < .001, η_p^2 = .20. Participants were better able to distinguish studied object identity information from lures when grid objects were associated by category (*M* = 3.06) as compared to unassociated (*M* = 2.36).

Main effects should be considered within the context of a three-way interaction between Spatial Organization, Category Association and Group, *F*(1, 62) = 4.56, *p* = .037, η_p^2 = .07. Planned comparisons using a Bonferroni corrected alpha value of .0125 were employed to examine the factors driving this interaction. For younger adults, when grids were spatially organized, category association did not impact memory (Means: Associated = 3.06, Unassociated = 2.87, *t* < 1); however, when grids were unorganized, younger adults demonstrated better memory on associated (*M* = 3.53), comparing to unassociated trials (*M* = 2.38), *t*(31) = 2.57, *p* = .012, *d* = .57 (see Fig. 3). On the contrary, older adults' object memory was influenced by category association only when with spatially organized grids (Means: Organized Associated = 2.82, Organized Unassociated = 1.67), *t*(31) = -2.92, *p* = .007, *d* = .69; Means: Unorganized Associated = 2.81, Unorganized Unassociated = 2.51, *t* < 1).

Analysis of mean object identity false alarms (collapsed across lure type) yielded a main effect of Category Association, *F*(1, 62) = 7.00, *p* = .01, η_p^2 = .10. Participants made more false alarms with associated (*M* = .17) than with unassociated grids (*M* = .12). We also found an interaction between Category Association and Group, *F*(1, 62) = 6.37, *p* = .014, η_p^2 = .09. As depicted in Fig. 4, when a Bonferroni

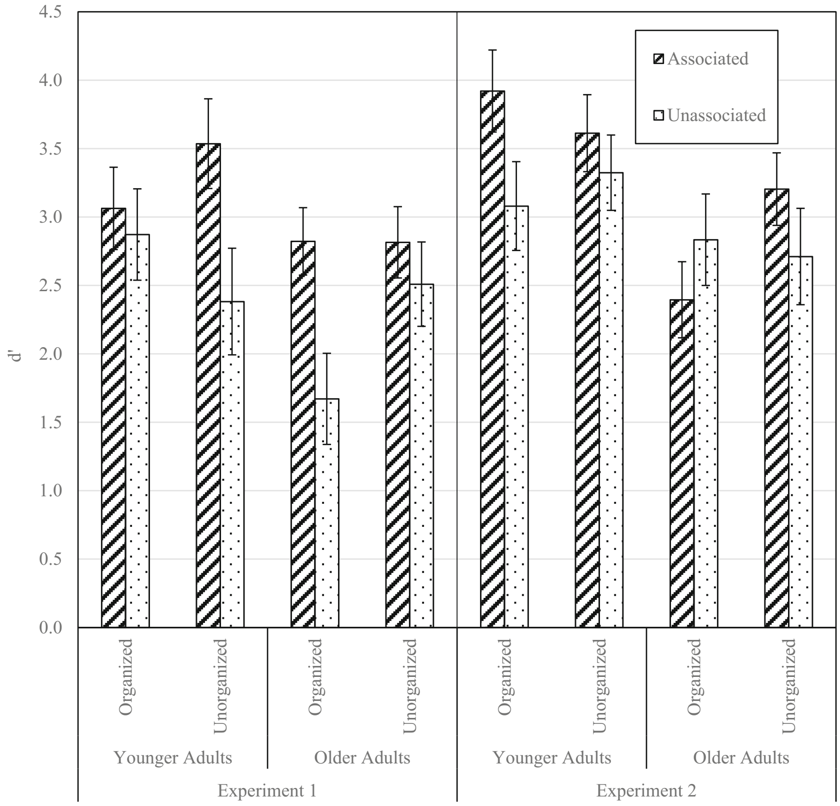


Fig. 3 Younger and older adults' object d′ by spatial organization (organized, unorganized) by category association (associated, unassociated), Experiments 1 and 2

corrected alpha of .025 was used, category association had no impact on young adult mean false alarm rates (Means: Associated = .14, Unassociated = .13, $t < 1$); however, older adults made significantly more false alarms when the grids were associated by category ($M = .20$) than when unassociated ($M = .10$), $t(31) = 3.89$, $p < .001$, $d = .75$.

Analyses on object βs yielded main effects of Spatial Organization, $F(1, 62) = 4.22$, $p = .04$, $\eta_p^2 = .06$, and

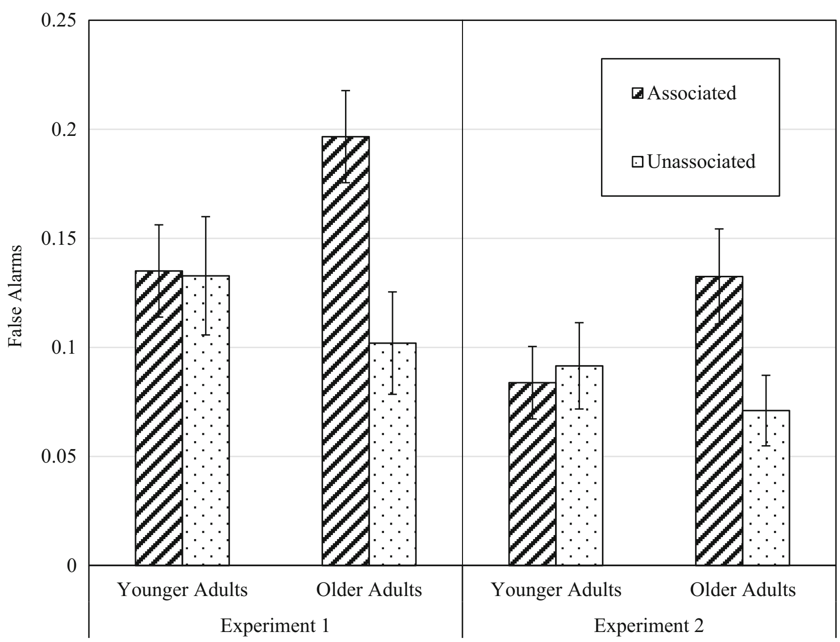


Fig. 4 Younger and older adults' object identity false alarms by category association (associated, unassociated), Experiments 1 and 2

Category Association, $F(1, 62) = 9.71$, $p = .003$, $\eta_p^2 = .14$. Spatial organization reduced participants' bias toward responding "*no*" on object trials (Means: Organized = 4.21, Unorganized = 7.10). Participants were also less biased to respond "*no*" when grid objects were associated by category ($M = 3.69$) than unassociated ($M = 7.63$).

Combination memory Results of mean d′ values yielded main effects of Spatial Organization, $F(1, 62) = 6.95$, $p = .011$, $\eta_p^2 = .10$, and Group, $F(1, 62) = 8.14$, $p = .006$, $\eta_p^2 = .12$. Spatial Organization increased memory for combination memory (Means: Organized = 2.22, Unorganized = 1.92). In addition, as depicted in Fig. 5, compared with younger adults ($M = 2.37$), older adults ($M = 1.77$) performed worse on questions assessing identity-location combined information. We also observed an interaction between Spatial Organization and Category Association, $F(1, 62) = 5.41$, $p = .023$, $\eta_p^2 = .08$. Using a Bonferroni corrected alpha value of .025, we found that participants performed better on grids that were organized and associated ($M = 2.46$) than those that were organized and unassociated ($M = 1.83$), $t(63) = 2.36$, $p = .02$, $d = .37$. No difference was found between the two unorganized conditions (Means: Unorganized Associated = 1.97, Unorganized Unassociated = 2.00, $t < 1$).

Mean false alarm rates (collapsed across lure type) yielded main effects of Spatial Organization, $F(1, 62) = 12.38$, $p = .001$, $\eta_p^2 = .17$, and Category Association , $F(1, 62) = 24.97$, $p < .001$, $\eta_p^2 = .29$. Specifically, spatial organization reduced participants' false alarm rates on combination trials (Means: Organized = .09, Unorganized = .13). Category Association, in contrast, increased combination false alarm rates (Means: Associated = .13, Unassociated = .09). The results also showed an interaction between Category Association and Group, $F(1, 62) = 8.16$, $p = .006$, $\eta_p^2 = .12$. T-tests using a Bonferroni corrected alpha value of .025 found that older adults were more likely to make false alarms when grid objects were associated ($M = .16$) than unassociated ($M = .09$), $t(31) = 5.57$, $p < .001$, $d = .62$. Young adults' performance, however, was not affected by category association, $t(31) = 1.50$, $p = .14$ (Means: Associated = .10, Unassociated = .08). We also found a three-way interaction between Spatial Organization, Category Association and Group, $F(1, 62) = 3.78$, $p = .05$, $\eta_p^2 = .06$. To examine the factors driving the interaction, comparisons using a Bonferroni corrected alpha value of .0125 were employed. As shown in Fig. 6, categorical relationships increased older adults' false alarms on combination trials, regardless of spatial organization. Compared with unassociated grids, older adults incorrectly recognized new information as being studied, when grids were associated categorically (Means: Organized Associated = .15, Organized Unassociated = .08, $t(31) = 5.15$, $p < .001$, $d = .70$; Unorganized Associated = .17, Unorganized Unassociated = .11, $t(31) = 3.64$, $p = .001$, $d = .44$). However, while younger adults' false alarm rates were not affected by categorical relationships (ts < 1), they produced fewer false alarms when grids were spatially organized, especially when the studied objects were associated (Means: Organized Associated = .07, Unorganized Associated = .14, $t(31) = 3.71$, $p < .001$, $d = .65$).

On combination βs, we found an interaction between Spatial Organization and Group, $F(1, 62) = 3.87$, $p = .05$,

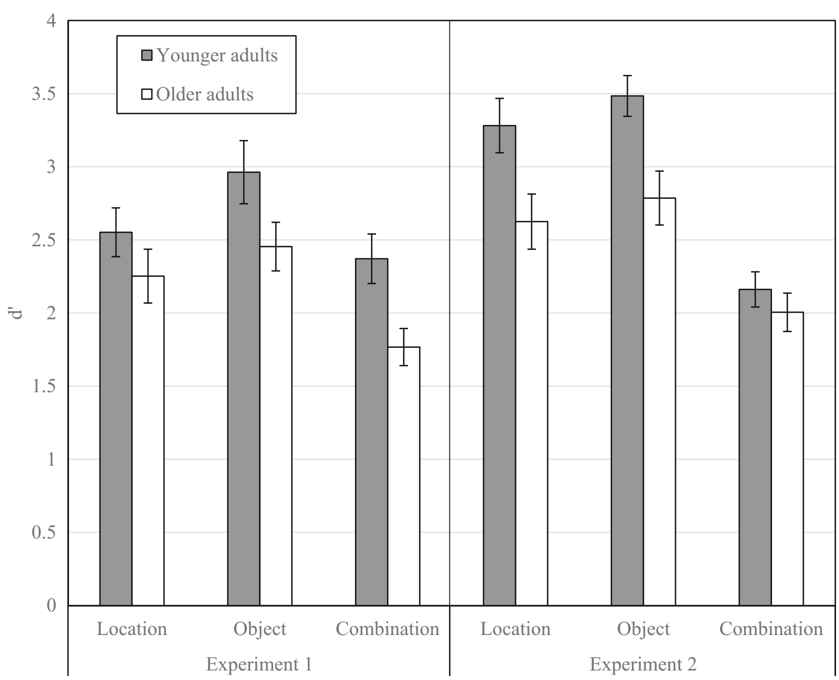


Fig. 5 Younger and older adults' d′ values for question types (location, object identity, and combination), Experiments 1 and 2

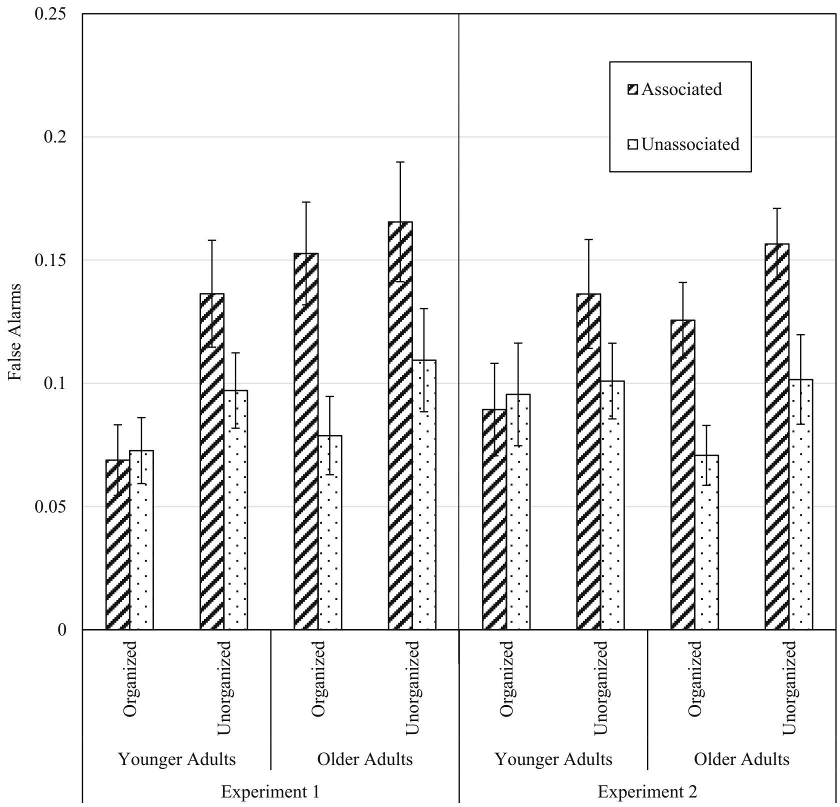


Fig. 6 Younger and older adults' combination false alarms by spatial organization (organized, unorganized) by category association (associated, unassociated), Experiments 1 and 2

η_p^2 = .06. Using a Bonferroni corrected alpha value of .025, follow-up T-tests found that younger adults were marginally affected by spatial organizations of the grid objects (Means: Organized = 7.92, Unorganized = 4.66, $t(31) = 2.09$, $p = .04$, $d = .45$); however, older adults were not impacted by Spatial Organization (Means: Organized = 5.48, Unorganized = 6.11, $t(31) = .52$, $p = .61$).

Discussion of Experiment 1

Experiment 1 demonstrated that spatial organization and category association differentially affect older and younger adults. The results suggest that for younger adults, categorical relationships of the objects may have been used to facilitate both object memory in the absence of spatial organization. This change in process suggests that younger adults may take advantage of a variety of organizing principles to support memory. However, this was not the case for older adults. Unlike younger adults, category associations helped the object memory of older adults only when grids were spatially organized. That is, older adults' object memory improved only when objects were both associated to a category and spatially organized. In addition, as suggested by object identity and combination false alarms results, older adults consistently made more false alarms when studied grids were associated by category. These results suggest that older adults may over-rely on, and even be biased by, categorical relationships, at least when memory for the object identity is relevant. On the other hand, false alarm rates associated with combination trials suggested that younger adults benefited more from spatial organization of the grids. In line with previous research (Thomas et al., 2012a), younger adults more effectively used spatial relationships within grids to reduce false alarms on combination trials. Analyses on combination β also suggested that comparing to older adults, younger adults were affected more by spatial relationships of the grid objects. Although age-related differences were found on object identity and combination trials, older adults performed as well as younger adults when location memory was tested individually.

Experiment 2

Experiment 2 examined whether blocking the task by question type would induce strategic processing. When grids were blocked by question types, participants, within each block, could strategically separate location from object identity information and more exclusively focus on to-be-tested information. Blocking by question type was expected to encourage participants to focus on processing relevant information in a given block, thereby improving performance. In Experiment

2, we hypothesized that trial-level manipulations of spatial and categorical relationships should still affect participants' performance, when trials were blocked to encourage strategic processing. We further hypothesized that both younger and older adults would benefit from task blocking. However, we expected the benefit in performance to be more pronounced for younger adults than older adults, because older adults may require explicit, rather than implicit, encouragement to strategically process information relevant to a specific question (cf., Craik, 1983). Indirectly encouraging task-relevant processing through blocking may not be sufficient for older adults to take advantage of the manipulation.

Methods

Participants A statistical power analysis (G*Power 3.1, Faul, Erdfelder, Lang, & Buchner, 2007) indicated that a sample size of 64 in Experiment 2 would be sufficient to detect effects of manipulations (power = .80, effect size = .25, alpha = .05).

A total of 64 participants took part in this experiment, including 32 younger adults (17 female and 15 male) and 32 older adults (21 female and 11 male). Younger adults, recruited from Tufts University, were students aged from 18 to 24 years (age M = 19.44, SD = 1.48; education M = 14.52 years, SD = 1.89; Shipley vocabulary test M = 13.44, SD = 1.83) and were given course credit for their participation. Older adults (aged between 60 and 83 years, M = 69.69, SD = 5.30; education M = 16.25 years, SD = 2.59; MMSE M = 28.25, SD = 2.37; Shipley vocabulary test M = 13.97, SD = 2.47) were community-dwelling older adults, recruited from an older-participants pool maintained by the Cognitive Aging and Memory Lab. They were paid US$15 per hour for participation.

Design The design and materials matched those used in Experiment 1.

Procedure All procedures were approved by the Tufts University SBER IRB. Experiment 2 had a similar procedure to Experiment 1, except that trials were blocked by question type instead of randomized. Block order was counterbalanced. Each block began with detailed instructions as to which kind of information participants should remember, followed by a series of trials asking the same questions. For instance, participants were instructed to "*remember in what locations the objects are presented*" in location block, and to "*remember what objects are presented*" in identity block; in combination block, they were asked to "*remember what objects are presented as well as in what locations the objects are presented.*" Trials were identical to Experiment 1, except that JOL questions targeted specific grid information. In the location block, the JOL questions were "*how likely are you to remember the locations of the objects in the previous grid?*"; in the identity block, the JOL questions were "*how likely are you to remember the objects shown in the previous grid?*"; and in the combination block, the JOL questions were "*how likely are you to remember the objects and the locations they were placed in the previous grid?*"

Results

Analyses for Experiment 2 matched those of Experiment 1. Memory was evaluated by examining d′ values, false alarm rates, and β values for location, object, and combination questions, respectively, using 2 (Spatial Organization: *Organized, Unorganized*) × 2 (Category Association: *Associated, Unassociated*) × 2 (Group: *Younger, Older*) mixed design ANOVAs.

Location memory Location trial d′ values yielded a main effect of Spatial Organization, $F(1,62) = 80.65$, $p < .001$, $\eta_p^2 = .57$. Participants could better distinguish learned location information from lures when the grids were organized (M = 3.95), compared to when unorganized (M = 1.96). Group was also significant, $F(1,62) = 6.14$, $p = .016$, $\eta_p^2 = .09$. As suggested in Fig. 5, when questions were blocked to promote strategic processing, younger adults (M = 3.28) had more accurate location memory than older adults (M = 2.63). We also observed an interaction between Spatial Organization and Category Association, $F(1,62) = 7.09$, $p = .01$, $\eta_p^2 = .10$. Comparisons using a Bonferroni corrected alpha value of .025 suggested that, with spatially organized grids, categorical relationships facilitated participants' ability to distinguish studied location information from lures (Means: Associated = 4.16, Unassociated = 3.73, $t(63) = 2.12$, $p = .025$, $d = .29$); however, when the grids were unorganized, category association did not impact location memory (Means: Associated = 1.67, Unassociated = 2.25, $t(63) = 1.94$, $p = .06$, see Table 1 for relevant means).

False alarm data yielded a main effect of Spatial Organization, $F(1, 62) = 66.80$, $p < .001$, $\eta_p^2 = .52$. Spatial organization reduced participants' location false alarm rates (Means: Organized = .04, Unorganized = .19). No other effects were found ($Fs < 2$).

Location β analyses showed no significant main effect or interaction.

Object identity memory Mean object identity d′ scores showed a main effect of Group, $F(1, 62) = 9.12$, $p = .004$, $\eta_p^2 = .13$. As shown in Fig. 5, older adults (M = 2.79) performed worse on object identity trials than younger adults (M = 3.48). No other main effects and interactions were found ($Fs < 2$).

Analysis of object identity false alarms showed an interaction between Category Association and Group, $F(1, 62) = 5.18$, $p = .026$, $\eta_p^2 = .08$. As suggested by T-tests

Table 1. Experiments 1 and 2, mean d′s of each question type, by grid conditions, by group

Experiment	Question type	Grid conditions			
		Organized Associated	Organized Unassociated	Unorganized Associated	Unorganized Unassociated
Experiment 1					
YAs	Location	3.99(.26)	3.12(.29)	1.67(.36)	1.43(.41)
	Object	3.06(.30)	2.87(.33)	3.53(.33)	2.38(.39)
	Combination	2.77(.23)	2.36(.26)	1.98(.20)	2.38(.28)
OAs	Location	3.53(.31)	2.83(.36)	1.19(.35)	1.46(.37)
	Object	2.82(.25)	1.67(.33)	2.81(.26)	2.51(.31)
	Combination	2.16(.20)	1.59(.21)	1.69(.21)	1.64(.18)
Experiment 2					
YAs	Location	4.58(.23)	4.13(.26)	2.22(.36)	2.20(.35)
	Object	3.92(.30)	3.08(.32)	3.61(.28)	3.32(.28)
	Combination	2.42(.21)	2.21(.15)	2.03(.20)	1.99(.19)
OAs	Location	3.74(.28)	3.34(.31)	1.13(.34)	2.30(.27)
	Object	2.40(.28)	2.83(.33)	3.20(.27)	2.71(.35)
	Combination	2.31(.21)	1.97(.26)	1.64(.23)	2.10(.17)

YAs = young adults, *OAs* = older adults

Standard errors are in parentheses

using a Bonferroni corrected alpha of .025, whereas younger adults' object false alarm rates were not affected by categorical relationships (Means: Associated = .08, Unassociated = .09, $t < 1$), older adults falsely recognized more lures when the grids were associated by category (M = .13) than when unassociated (M = .07), $t(31) = 2.77$, p = .01, d = .57.

Analyses on object β values showed no significant main effect or interaction.

Combination memory Mean d′ scores associated with combination trials yielded a main effect of Spatial Organization, $F(1, 62) = 5.15$, $p = .027$, $\eta_p^2 = .08$. Participants' ability to distinguish learned identity-location combined information from lures was better when the grids were organized spatially (Means: Organized = 2.23, Unorganized = 1.94). No other main effects and interactions were found ($Fs < 2$).

Combination false alarm scores showed main effects of Spatial Organization and Category Association [$F(1, 62) = 9.91$, $p = .003$, $\eta_p^2 = .14$; $F(1, 62) = 11.81$, $p = .001$, $\eta_p^2 = .16$]. Specifically, spatial organization reduced combination false alarms (Means: Organized = .09, Unorganized = .12). Category Association, however, tended to increase false alarms with combination trials (Means: Associated = .13, Unassociated = .09). Finally, we found an interaction between Category Association and Group, $F(1, 62) = 3.98$, $p = .05$, $\eta_p^2 = .06$. Older adults made more false alarms when grid objects were associated ($M = .14$) than unassociated ($M = .09$), $t(31) = 4.51$, $p < .001$, $d = .83$, whereas young adults' performance was not affected by categorical relationships, $t < 1$ (Means: Associated = .11, Unassociated = .10).

Analyses on combination βs yielded main effects of Spatial Organization, $F(1, 62) = 4.21$, $p = .044$, $\eta_p^2 = .06$, and Category Association, $F(1, 62) = 7.54$, $p = .008$, $\eta_p^2 = .11$. Participants' bias toward responding "*no*" on combination trials was affected by spatial relationships of the grid objects (Means: Organized = 7.45, Unorganized = 5.41). In addition, participants were less likely to respond "*no*" with associated ($M = 4.89$) than unassociated grids ($M = 7.96$). We also observed an interaction between Category Association and Group, $F(1, 62) = 4.01$, $p = .05$, $\eta_p^2 = .06$. T-tests using a Bonferroni corrected alpha value of .025 found that older adults were more biased toward responding "*yes*" when grid objects were categorically associated ($M = 2.92$) comparing to unassociated ($M = 8.22$), $t(31) = 3.57$, $p = .001$, $d = .84$; however, younger adults were not affected by Categorical Association (Means: Associated = 6.87, Unassociated = 7.70, $t(31) = .50$, $p = .62$).

Discussion of Experiment 2

Experiment 2 demonstrated that when encouraged to strategically process task-relevant information, both spatial and categorical relationships affected participants' performance. Consistent with our hypothesis, spatial organization facilitated location memory and combination memory for both age groups. However, unlike in Experiment 1, association by category did not facilitate object memory performance, suggesting that blocking by question may impact how participants use category association to support memory. Consistent with previous studies and with Experiment 1, older adults made more false alarms on object and combination trials, when grid objects were associated by category. Combination β analyses also suggested that comparing with younger adults, older adults were more likely to respond "*yes*" with categorically associated grids, indicating an over-reliance on categorical relationships. In addition, with blocking to encourage strategic processing, younger adults performed significantly better than older adults on location and object identity memory. These data suggest that younger adults may be able to take advantage of the indirect facilitation offered by blocking more so than older adults, at least when a single component of visual-spatial information is assessed.

Comparisons between Experiment 1 and Experiment 2

Although the results of Experiments 1 and 2 demonstrate that trial-level organization influences both older and younger adult performance, without a direct comparison of the results of the two experiments, we cannot provide inferential evidence to support the hypothesis that blocking by question also influenced VSWM. The methodology of Experiments 1 and 2 varied only by how blocks were organized. In Experiment 1, trial blocks were randomized such that participants could not predict what information would be assessed. In Experiment 2, trials were blocked by the information queried, such that all location trials were presented in one block, all object trials were presented in one block, and all combination trials were presented in one block. We hypothesized that this simple manipulation between the two experiments would differentially impact older and younger adults. The cross-experiment comparisons presented in the following section provide statistical evidence for this hypothesis.

Results

Cross-experiment comparisons were conducted using 2 (Spatial Organization: *Organized, Unorganized*) × 2 (Category Association: *Associated, Unassociated*) × 2 (Group: *Younger, Older*) × 2 (Blocking: *Random, Blocked*) mixed design ANOVAs on d′ and β for each trial type.

Location memory Location trial cross-experiment comparisons on d′ scores yielded main effects of Spatial Organization, $F(1, 124) = 138.05$, $p < .001$, $\eta_p^2 = .53$, Group, $F(1, 124) = 6.92$, $p = .01$, $\eta_p^2 = .05$, and Blocking, $F(1, 124) = 9.19$, $p = .003$, $\eta_p^2 = .07$. Across both experiments, participants better remembered location information with organized ($M = 3.66$) compared with unorganized grids ($M = 1.70$). Younger adults ($M = 2.92$) performed better than older adults ($M = 2.44$) on location trials. Participants also demonstrated better location memory when trials were blocked ($M = 2.95$) in Experiment 2, compared with randomized trials in Experiment 1 ($M = 2.40$), suggesting a facilitative effect of blocking on location memory. An interaction between Spatial Organization and Category Association was also observed, $F(1, 124) = 8.72$, $p = .004$, $\eta_p^2 = .07$. T-tests using a Bonferroni corrected alpha value of .025 suggested that participants performed better on grids that were both organized and associated ($M = 3.96$) than those that were organized and unassociated ($M = 3.35$), $t(127) = 3.50$, $p < .001$, $d = .37$. No difference emerged between unorganized-associated grids ($M = 1.55$) and unorganized-unassociated grids ($M = 1.85$, $t(127) = 1.26$, $p = .21$).

Cross-experiment comparisons on location β showed no significant main effect or interaction.

Object memory Cross-experiment comparisons on object d′ scores found main effects of Category Association, $F(1, 124) = 12.92$, $p < .001$, $\eta_p^2 = .09$, Group, $F(1, 124) = 11.40$, $p = .009$, $\eta_p^2 = .08$, and Blocking, $F(1, 124) = 5.70$, $p = .019$, $\eta_p^2 = .04$. Across experiments, participants were better able to remember object identity information when objects in the grids were associated by category ($M = 3.17$) compared with unassociated ($M = 2.67$). Age also affected object memory, with younger adults ($M = 3.22$) demonstrating better object memory than older adults ($M = 2.62$). Additionally, blocking facilitated object memory, as participants remembered object identity information better when trials were blocked (Experiment 2 $M = 3.14$) than when trials were randomized (Experiment 1 $M = 2.71$).

Cross-experiment comparison also yielded a four-way interaction between Spatial Organization, Category Association, Group, and Blocking, $F(1, 124) = 7.10$, $p = .009$, $\eta_p^2 = .05$. As depicted in Fig. 3, in Experiment 1, categorical relationships of the grids helped younger adults' object memory mainly with unorganized grids, $t(31) = 2.57$, $p = .012$, $d = .57$. However, these relationships only facilitated older adults with spatially organized grids, $t(31) = 2.92$, $p = .007$, $d = .69$. Alternatively, in Experiment 2 where trials were blocked, no significant differences emerged between different grid conditions, suggesting that blocking might have differentially affected younger and older adults in the way they used spatial and categorical relationships.

Cross-experiment analyses on object β showed a main effect of Category Association, $F(1, 124) = 5.99$, $p = .02$, $\eta_p^2 = .05$. Across experiments, participants were less likely to respond "*no*" on associated grids ($M = 5.01$) as compared to unassociated grids ($M = 7.42$).

Combination memory Results of cross-experiment comparisons on mean combination d′ values yielded main effects of Spatial Organization, $F(1, 124) = 11.88$, $p = .001$, $\eta_p^2 = .09$, and Group, $F(1, 124) = 7.55$, $p = .007$, $\eta_p^2 = .06$. Across experiments, spatial organization increased participants' memory of identity-location combined information (Means: Organized = 2.22, Unorganized = 1.93). Age also impacted combination memory, with younger adults ($M = 2.27$) performing better than older adults ($M = 1.89$). In addition, we observed an interaction between Spatial Organization and Category Association, $F(1, 124) = 7.72$, $p = .006$, $\eta_p^2 = .06$. Using Bonferroni corrected alpha value of .025, we found that participants remembered combination information better on grids that were both organized and associated ($M = 2.42$) than those that were organized and unassociated ($M = 2.03$), $t(127) = 2.70$, $p = .008$, $d = .31$. No difference was found between the two unorganized conditions (Means: Unorganized Associated = 1.84, Unorganized Unassociated = 2.02, $t(127) = 1.36$, $p = .18$).

On combination βs, we found main effects of Spatial Organization, $F(1, 124) = 5.72$, $p = .02$, $\eta_p^2 = .04$, and Category Association, $F(1, 124) = 5.01$, $p = .03$, $\eta_p^2 = .04$. Across both experiments, participants were more biased towards responding "*no*" when the grids were organized into spatial configurations ($M = 7.07$) than unorganized grids ($M = 5.40$). In addition, on categorically associated grids, participants were more biased towards the "*yes*" response ($M = 5.34$), comparing to unassociated grids ($M = 7.13$). We also observed an interaction between Spatial organization and Groups, $F(1, 124) = 5.00$, $p = .03$, $\eta_p^2 = .04$. T-tests using a Bonferroni corrected alpha value of .025 showed that younger adults' performance was biased by Spatial Organization (Means: Organized = 8.41, Unorganized = 5.17, $t(63) = 3.22$, $p = .002$, $d = .46$), whereas older adults were not affected by spatial relationships of the grids, $t < 1$ (Means: Organized = 5.74, Unorganized = 5.63). Lastly, Category Association also interacted with Group, $F(1, 124) = 5.30$, $p = .02$, $\eta_p^2 = .04$. Across experiments, older adults were biased towards responding "*yes*" when grids were associated ($M = 3.88$) comparing to unassociated grids ($M = 7.49$), $t(63) = 3.28$, $p = .002$, $d = .52$, whereas younger adults were not affected by categorical relationships, $t < 1$ (Means: Associated = 6.81, Unassociated = 6.76).

Discussion of cross-experiment comparisons

Our findings in cross-experiment comparisons suggest that encouraging strategic processing through blocking influences location and object memory. In addition, we found that blocking differentially impacted older and younger adult performance on object memory trials. In Experiment 1, categorical relationships helped younger adults in the absence of spatial organization, suggesting that younger adults are flexible in taking advantage of different relationships to support memory. However, category associations helped older adults only when grids were spatially organized, suggesting that older adults might only be able to benefit from categorical relationships when the effort to encode grid information was reduced by spatial organizations. Blocking in Experiment 2 eliminated this age group difference, indicating that encouraging strategic processing might have differentially affected the way younger and older adults use spatial and categorical relationships in object memory.

In addition, for combination memory, the age-related deficit found in Experiment 1 was eliminated in Experiment 2. However, the interaction between Group and Experiment was not statistically significant ($p = .108$), suggesting that on combination trials blocking may have little influence. We will further discuss the effect of blocking in the general discussion.

General discussion

The present study explored whether and how VSWM declines with age, and whether VSWM processes could be facilitated by organizing the trial (Experiment 1) and by organizing the task (Experiment 2). Towards this end, we included two trial-level manipulations (spatial organization and category association) to facilitate spatial and object identity processing, and a task-level manipulation (blocking) to indirectly encourage strategic processing. Although studies have examined how spatial organization affects younger adults' VSWM (e.g. Taylor et al., 2014), the present study contributes to the existing literature by extending this finding to an older population. The present study is also among the first to investigate the combination of spatial organization, categorical relationships, and task organization on younger and older adults' VSWM.

Consistent with our hypotheses, we found that trial-level manipulations (spatial organization and category association) affected VSWM. Generally, spatial organization helped location memory whereas category association benefited object identity memory, which is in line with studies suggesting an advantage of global patterns on location and/or object identity processing (Navon, 1977; Taylor et al., 2014; Thomas et al., 2012a). One possible explanation of this facilitative effect could be that spatially organizing or categorically associating objects may reduce cognitive load in VSWM processing. As suggested by research demonstrating improved memory with Gestalt principles such as proximity (Woodman, Vecera, & Luck, 2003), hierarchical or global structures like spatial and categorical relationships may help to eliminate stimuli redundancies and reduce information load associated with learning (Brady, Konkle, & Alvarez, 2009; Morey, Cong, Zheng, Price, & Morey, 2015). Thus, spatial and categorical relationships within a grid should lead to more accurate memory for locations and/or object identities.

Another goal of the present study was to explore age-related differences in VSWM. In Experiment 1, where trials were randomized and strategic processing was limited, age-related differences were observed on object identity and combination trials, but not on location memory trials. That is, compared with younger adults, older participants had equally good memory for location information, but demonstrated age-related differences on object identity and combination questions. Whereas this finding is in line with previous literature suggesting that location processing may be automatic or less effortful than object processing (Ellis, Katz, & Williams, 1987; Mandler et al., 1977), it may not be consistent with previous study that showed age-related deficits across all VSWM components (Thomas et al., 2012b). However, there are important differences between the current study and the Thomas et al. (2012a, b) study. For example, the stimuli objects were different. Thomas and colleagues (2012a, b) used simple line drawings, whereas in the present study, we used colored objects with categorical relationships, which might provide additional memory support for older adults. Experiment procedures were also different. In Thomas et al. (2012a, b), participants studied 5 × 5 grids containing between two and five objects, in a completely randomized order; however, in the current study, the number of to-be-learned objects in each grid was kept constant—each grid contained five objects. Regular and unpredicted changes in the number of stimuli within a grid may have caused additional burdens to processing that may have negatively impacted older adult performance. Therefore, these differences in the design might also have contributed to the discrepancy found between the current study and the previous study.

When the task was blocked to promote strategic processing in Experiment 2, age-related differences were observed in both location and object identity memory, but not in combination memory. Comparing with Experiment 1, younger adults performed slightly worse on combination memory, whereas older adults performed slightly better combination memory in Experiment 2. However, cross-experiment comparisons found that the interaction between Group and Experiment was not statistically significant. Blocking did not facilitate combination memory for either group. We suggest that blocking may not have influenced combination memory performance, because of the complexity of the task. Successful performance on combination trials requires that participants bind object and location information. Considering that blocking only indirectly encouraged strategic processing by allowing participants to anticipate what information is to be remembered, the influence of blocking may be limited to trials in which a single attribute is the anticipated to-be-learned information.

Results of cross-experiment comparisons supported our hypothesis that blocking could facilitate participants' location memory and object memory. It is possible that randomly presenting different question types in Experiment 1 required participants to simultaneously maintain both location and identity information, making the task more cognitive demanding comparing to Experiment 2. The random JOL questions that followed the grids in Experiment 1 might also increase the cognitive work load for participants. Therefore, being able to strategically process task-relevant information in Experiment 2 improved participants' individual VSWM processing. More importantly, blocking seemed to differentially affect younger adults and their older counterparts, resulting in age-related differences on location and object trials. One possible account is that, older adults may be less efficient than younger adults to strategically process task-relevant VSWM information. Therefore, they may be less likely to benefit from task blocking to encourage strategic processing. However, strategic processing was never directly or explicitly promoted in Experiment 2. Older adults may derive fewer benefits from blocking, because such a manipulation only implicitly facilitates strategic processing. According to previous research, older adults more likely benefit from explicit environmental support. For example, Thomas and Bulevich (2006) found that older adults reduced source misattribution errors when explicitly instructed to evaluate relevant source attributes. Similarly, Thomas and Millar (2012) found that older adults were more likely to rely on strategic decision making when explicitly directed to do so. Finally, Thomas and colleagues found that explicit instructions on how to approach a map learning task improved older adult map memory (Thomas et al., 2012a). The finding that older adults may need explicit external cues with spatial memory adds to evidence that contexts in which spatial memory is important likely need increased environmental support (Ross & Schryer, 2015).

Previous findings also suggest that spatial and categorical relationships may differentially affect younger and older adults' memory for visuo-spatial information. More specifically, younger adults, who spontaneously organize information in map studies (Thomas et al., 2012a), may be better at taking advantage of the spatial relationships to facilitate recall; older adults, on the contrary, may rely more heavily on categorical information to support memory performance (Fernandes & Grady, 2008; Tun, et al., 1998). Results of false-alarm and β analyses in the present study supported the selective effect of the trial-level manipulations on younger and older adults' VSWM, that is, younger adults benefited more from spatial organization, whereas older adults rely more on, or even be biased by, categorical relationships in VSWM. Taken together, these findings may suggest an age-related shift in ease of using VSWM components. Compared with younger adults, older adults tend to have better vocabulary due to their accumulated exposure to language (Kavé & Halamish, 2015). Increased vocabulary with age may ease categorical processing, leading to a shift away from spatial processing.

We should also note one factor that might have affected findings in the present study. Participants made judgments of learning (JOLs) between study and test. We included these JOLs to examine younger and older adults' metacognition, but because this paper focuses mainly on VSWM, JOL data are not presented in this report. Nonetheless, including these JOLs might have impacted the results. Making JOLs between the study and test phases might have affected memory, especially for older adults, perhaps related to increased cognitive demands of making a JOL that in turn negatively affect retrieval. However, because one JOL question followed each studied grid, the effect would be present across all trials and conditions for all participants. Further, as found in previous studies (Thomas et al., 2012b), both younger and older adults were able to engage in a VSWM task following an inter-trial JOL. Future studies can introduce a short delay between study and test to replace the JOL questions, to reduce the impact of JOLs on participants' memory performance.

Conclusion

The present study sought to explore how aging affects VSWM processing, and whether location and object identity memory could be facilitated by trial-level or task-level manipulations. In two experiments, we systematically manipulated spatial organization, category association, and strategic processing in a VSWM paradigm, examining and comparing younger and older adults. We found that both age groups benefited from trial and task organizations, but the effects differ by age. In addition, older adults showed less facilitation from the task-level organization (blocking), potentially suggesting that they may be less efficient than younger adults in strategic processing, and therefore more explicit environment supports in VSWM may be needed.

Although many studies have explored how aging and environmental factors influence VSWM, the present study is among the first to explore how spatial organization, categorical relationships as well as strategic processing may, both individually and interactively, affect younger and older adults' VSWM. Therefore, it has important implications for understanding how aging affects VSWM processing, and how to facilitate VSWM in an effective and efficient way.

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