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Memory for Important Item-Location Associations in Younger and Older Adults

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Abstract

Older adults typically experience memory impairments for verbal and visuospatial episodic information, which are most pronounced for associative information. While some age-related verbal memory deficits may be reduced by selectively focusing on high-value item information, the binding of items to locations in visuospatial memory involves different processes that are impaired in older adults. In the current study, we examined whether age-related impairment in visuospatial binding could be alleviated by strategic focus on important information and whether varying study time and presentation formats would affect such selectivity. We also used novel spatial resolutions analysis to examine participants' gist-based visuospatial memory with respect to information importance. Younger and older adults were presented with items worth different point values in a visuospatial display, either sequentially (Experiment 1) or simultaneously (Experiment 2). When items were presented sequentially, participants became more selective with task experience, but when items were presented simultaneously, selectivity was maintained throughout the task. These patterns were also observed when encoding time was reduced for younger adults. Although older adults successfully engaged in value-based memory strategies, age-related visuospatial memory deficits were still present, even for high-value information, consistent with the associative deficit hypothesis. However, under some conditions, older adults showed reduced spatial relocation errors for high-value item-location associations. The results suggest that strategic control can be utilized when binding information in visuospatial memory, and that both younger and older adults can benefit by focusing on high-value items and their locations, despite associative memory deficits present in old age.

Keywords

associative memory; presentation format; selectivity; visuospatial memory

Older adults tend to experience declines in visuospatial memory, the ability to remember *what* and *where* objects are in the environment (e.g., Park et al., 2002). These declines have been attributed to age-related associative memory deficits. In order to successfully remember visuospatial information, one must effectively encode and later retrieve the association between relevant visual and spatial information. As such, visuospatial memory failures may be due to inaccurate memory for individual features (the identity or location of an item), an

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inability to effectively associate these features in memory, or both. While prior research has found age-related impairments in both individual visual (Park et al., 2002; Vaughan & Hartman, 2010) and spatial (Light & Zelinski, 1983; Pezdek, 1983) component memory, the current study is primarily interested in deficits in remembering visuospatial associations.

Studies investigating visuospatial memory consistently find larger age-related impairments when the binding of visual and spatial features is required relative to memory for single features (e.g., Chalfonte & Johnson, 1996; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000; Thomas, Bonura, Taylor, & Brunyé, 2012). These impairments in visuospatial binding are likely reflective of a more general associative deficit such that older adults' episodic memory deficits are largest when multiple features are required to be linked, or bound, in memory. This associative deficit found in visuospatial memory has also been replicated using a variety of materials including word pairs (Castel & Craik, 2003; Naveh-Benjamin, 2000), word-nonword pairs (Naveh-Benjamin, 2000), word-face pairs (Overman & Becker, 2009), name-face pairs (Naveh-Benjamin, Guez, Kilb, & Reedy, 2004), face pairs (Rhodes, Castel, & Jacoby, 2008), picture pairs (Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003) and object-location pairs (Cowan, Naveh-Benjamin, Kilb, & Saults, 2006). As such, binding deficits seem to be a consistent driving force behind visuospatial memory impairment in older adults (see also Old & Naveh-Benjamin (2008) for a detailed meta-analysis examining the associative deficit hypothesis under various conditions).

The mechanism underlying visuospatial binding impairments in old age may be informed by theories of visual attention. The feature integration theory (FIT; Treisman & Gelade, 1980; Treisman & Sato, 1990) posits that there are two stages when conducting visual search: the preattentive stage and focused attention stage. When searching for an object within an array, the preattentive stage is parallel and automatic, which is sufficient when identifying single features of an object. However, when searching for conjunctions of features, the focused attention stage is required in which features are combined in a serial and effortful process. The feature integration theory asserts that attention acts like a "glue" which integrates the independent features of an object into a coherent whole. Interpreted in the context of visuospatial memory, the binding of object identity and location information into a solitary unit in memory may be more cognitively demanding than memory for single feature memory (i.e., identity *or* location) due to the serial and effortful allocation of attention that is required. This may lead to disproportionate visuospatial binding deficits in older adults who tend to have impairments in attentional and processing resources (Castel & Craik, 2003; Craik & Byrd, 1982). It is important to note that the role of attentional impairments in associative binding deficits has been called into question (Smyth & Naveh-Benjamin, 2016; see also Naveh-Benjamin & Smyth, 2016). However, the aforementioned study utilized verbal, not visual materials to assess the role of attention in associative memory. While attention may not be crucial to the binding of verbal information, it is likely that visuospatial binding does require significant attentional resources. In line with predictions made by FIT, various studies have found that binding multiple features in visual memory is disrupted by concurrent divided attention tasks (Fougnie & Marois, 2009; Postma & De Haan, 1996; Treisman & Zhang, 2006; cf. Allen, Baddeley, & Hitch, 2006; Brown & Brockmole, 2010), suggesting that the mechanism underlying successful visuospatial memory may be reliant upon the availability of attentional resources at encoding.

While memory deficits are certainly present throughout old age, some studies have demonstrated that older adults are able to strategically utilize their available cognitive resources. Prior research in the domain of memory selectivity has shown that older adults are able to focus on high-value items at the expense of competing low-value items, a process termed value-directed remembering (VDR; Castel, Benjamin, Craik, & Watkins, 2002; Castel, 2008). In this verbal item-based experimental paradigm, older and younger adults were shown a list of 12 unrelated words, each paired with a point value 1–12. Participants were told that they would receive the point value associated with a word if they correctly remembered it and that their goal was to maximize their score (the summation of all the points associated with correctly remembered words). Although the older adults remembered a lesser proportion of the lower value words (values 1–9) during recall, they remembered the same proportion of high-value words (values 10–12) as the younger adults. Older adults, aware of their limited memory capacity, were able to selectively attend to and remember the high-value words in order to maximize their score. So, while older adults remembered a lesser proportion of words overall, they were able to compensate for age-related memory deficits by focusing on the important information to boost their point scores. Importantly, the ability to selectively remember high-value information is dependent upon the strategic control of attention at encoding (Castel, 2008). This notion is further supported by evidence demonstrating that those with deficits in attentional resources like children with attention-deficit/hyperactivity disorder (ADHD) and older adults with very mild to mild Alzheimer's disease are less selective than healthy controls (Castel, Balota, & McCabe, 2009; Castel, Lee, Humphreys, & Moore, 2011).

Prior work has investigated how value may influence associative memory for verbal information. Ariel, Price, and Hertzog (2015) used a VDR paradigm to investigate the effect of value on younger and older adults' ability to bind unrelated word pairs of differing value. Older adults' use of strategic control processes may not be impaired when required to remember associated information because 1) older adults' metacognitive monitoring ability (used to make study decisions) may be spared in old age (Hertzog, 2016) and 2) older adults' beliefs about age-related memory impairment may encourage them to use value-based strategies to remember the most important information (Dixon & de Frias, 2007). However, their results showed that while both younger and older adults remembered more high- than low-value word pairs, an age-related associative deficit was still present for information of all values. So, while both groups of participants were able to use strategic attentional control processes to guide their memory for associations, age-related deficits still emerged, even for high-value information. This suggests that while value can guide older adults' memory for single items and associations between multiple items, the memorial benefit for high-value information may not be as great when required to bind multiple features, at least for verbal information.

Another important factor that may influence the binding of information in visuospatial memory is the format in which the information is encountered. In daily life, we may encounter information that is present in the environment at the same time (i.e., simultaneously), or we may encounter information in some sequence (i.e., sequentially). Prior research has investigated this distinction between simultaneous and sequential presentation of stimuli and its effect on binding ability. Allen and colleagues (2006) found that when younger adults were presented items with multiple visual features, memory for the combination of features was significantly impaired when the items were presented sequentially, as compared to simultaneously. This deficit may have occurred because binding features of an item requires significant attentional resources (in line with FIT; Treisman & Gelade, 1980) and that, in the sequential presentation condition, associations were more prone to interference from other items (both retroactively and proactively), although this was not examined in older adults. Brown and Brockmole (2010) theorized that this deficit in binding for sequentially presented items would be more drastic for older adults, as compared to younger adults. Older adults may have diminished attentional resources (Zacks & Hasher, 1988) and because binding features of items that are presented sequentially requires significant attentional resources, it is reasonable to hypothesize that older adults may show more pronounced deficits than their younger adult counterparts. However, while overall binding deficits were found compared to the simultaneous presentation, the sequential presentation format did not differentially affect younger and older adults. Thus, increased attentional load may not lead to greater age-related binding deficits in all cases.

Presentation format may also affect participants' ability to engage in value-based study strategies, especially for older adults who may have reduced attentional resources (Castel & Craik, 2003). Research on the agenda-based regulation model (Ariel, Dunlosky, & Bailey, 2009) may provide valuable insight regarding how presentation type may interact with value to affect memory. The agenda-based regulation model predicts that participants are able to use agendas based on task constraints and goals to make decisions about selecting particular items to study. In the VDR paradigm described previously, for example, participants' agenda may be to remember as many high-value words as possible in order to achieve their goal (i.e., maximize their score). Dunlosky and Thiede (2004) found that participants were able to successfully carry out their agenda (in this case studying easier items from a list) when items were presented simultaneously. When items were presented sequentially, however, participants were forced to abandon their agenda (and study more difficult items). Participants were unable to execute their goal-relevant strategy during sequential presentation because they were unable to make comparisons across items in order to select specific ones to study. Instead, participants were forced to make item-by-item selection decisions, which may have distracted them from their overall agenda. As younger adults face challenges carrying out value-based strategies on sequentially presented materials (Robison & Unsworth, 2017), older adults, with less available processing resources, may also have significant impairments. It is important to note that some of the aforementioned studies examined short-term/working memory, while the current study investigates the effects of presentation format on long-term memory.

The Current Study

While value can influence free recall (Castel et al., 2002) and recognition (Hennessee, Castel, & Knowlton, 2017) in both younger and older adults, it is it is unclear how the attentionally-demanding binding of information in a visuospatial context could be influenced by information importance and the strategic control processes that guide what people try to remember. The goal of the current experiments then was to clarify how value may affect the binding of item identity and location information, whether this effect varies between younger and older adults, and how presentation format may differentially affect participants' visuospatial binding ability. Building on prior work that has examined how value influences memory for verbal materials (Castel et al., 2002; Hayes, Kelly, & Smith, 2013; Robison, & Unsworth, 2017), we developed a novel paradigm to test how value could influence memory for items and their spatial locations to determine how the strategic control of attention at encoding may influence the binding of information in visuospatial memory. This paradigm also allowed for the systematic investigation of the pattern of errors produced by using a measurement of spatial "relocation error" or spatial displacement (i.e., how far participants misplaced an item from its target location). Using this measure, we were able to investigate older adults' use of visuospatial memory in a gist-based manner when they were unable to retrieve an exact memory trace. In the verbal domain, there is evidence that older adults may be more likely to rely on gist-based memory than younger adults (e.g., Brainerd & Reyna, 2001; Koutstaal, 2006; Reder, Wible, & Martin, 1986). Extending the work in the verbal domain, the findings obtained in the current study represented a more precise measure spatial displacement and allowed us to investigate how visuospatial gist memory might vary as a function of age and information importance. In the present task, we refer to this novel measure of gist-based spatial memory as spatial resolution.

Given the well-established deficits in both individual visual and spatial memory found in older adults, the current study was specifically interested in age-related changes in the binding, or associative, mechanism underlying visuospatial memory. As such, the experimental paradigm used here does not examine component memory (item identity or location) individually, but rather the association between the two. As the binding aspect of visuospatial memory is particularly taxing on attentional resources, we wanted to determine whether visuospatial associative deficits could be alleviated with the usage of value-based study strategies by older adults. Such selectivity would imply that older adults could effectively allocate attention during encoding even in a particularly attention-dependent visuospatial memory task.

Older adults' associative memory for items and their locations could be influenced by value in several ways. First, given significant binding deficits in old age (Chalfonte & Johnson, 1996; Thomas et al., 2012), it is entirely possible that older adults may not be able to use value to guide their visuospatial memory. That is, whereas older adults are able to selectively focus on high-value information for verbal materials (that do not require the binding of multiple features) or associations between verbal information, they may not be able to do so in the context of a more resource-demanding task (binding items to locations) and thus remember all information at a similar rate. Second, similar to findings by Ariel et al. (2015), older adults may be able to use strategic control processes to remember associations, but age-related deficits for associated high-value information may not be completely eliminated. That is, older adults may be able to use value to guide their memory for associated visual and spatial information, but still remember less high-value information than younger adults. It is possible that larger age-related deficits emerge when required to bind visual and spatial information, as compared to the word pairs used by Ariel et al. (2015). Even though the concrete noun-noun pairs were semantically unrelated (e.g., *icebox-elephant*), participants may have still been able to elaborately encode pairs by forming rich mental images (e.g., a shivering elephant sitting in an icebox), whose later retrieval has been shown to increase memory of associated information for both younger and older adults (Naveh-Benjamin, Brav, & Levy, 2007; Richardson, 1998). However, this elaborative encoding strategy may not be possible when attempting to bind item and location pairs. In contrast to concrete noun pairs, forming a vivid mental image of an item in a bare visuospatial array (simple grids in the current study) may be much more difficult. As such, testing memory for items and locations may be a more “pure” test of that association, rather than a test for an elaborately encoded mental image. Third, older adults may be able to use value to eliminate age-related associative memory deficits for high-value information. That is, older adults may show similar patterns of selectivity found in previous VDR tasks using verbal materials to remember the same proportion of high-value information as younger adults (Castel et al., 2002).

Experiment 1

In Experiment 1, we examined younger and older adults’ ability to bind item and location features for sequentially presented information in a visuospatial memory task. We were interested in whether older adults would be able to use strategic control processes to alleviate age-related associative memory deficits in the context of visuospatial memory and how strategy use might change with increasing task experience. To do so, we presented two groups of younger adults (with varying presentation times) and older adults with a grid containing items paired with point value. After viewing the grid, participants were given a memory test in which they were required to place items into their previously viewed locations and were then given feedback on their performance. Participants then repeated this procedure for a total of twelve study-test cycles, with unique item-location pairs in each grid.

We hypothesized that both younger and older adults would be able to use strategic control processes to guide their visuospatial binding. However, given prior research, we expected that age-related deficits would still emerge for information of all values. We expected that the sequential presentation of items, the need to bind items to locations, and implementation of value-based study strategies would tax attentional resources during encoding, especially for older adults. Due to this, we expected age-related binding deficits to occur for information of all values. However, similar to results obtained in prior VDR tasks, we also predicted that participants would exhibit greater selectivity with continued task experience, as strategy use may have become more refined as participants completed trials and received feedback on their performance.

In addition to a group of younger adults and older adults matched on presentation time (30s), we also included a younger adult group that was presented with information for half the duration (15s). By placing a group of younger adults under time constraints, we hoped to examine how their overall memory and selectivity would compare to older adults who tend to remember less information overall, but are also able to effectively execute value-based memory strategies. Prior research using verbal materials has found that a reduction in presentation time lowers overall memory, but does not affect younger adults’ ability to selectively focus on and later remember high-value information (Middlebrooks, Murayama, & Castel, 2016). However, other research has shown that limiting study time may lead to less efficient execution of value-based agendas in younger adults (Ariel & Dunlosky, 2013), although neither of the previously mentioned studies required participants to encode associated or visuospatial information under time constraints. Given that participants tend to have worse memory for associated features of an item compared to single features, it may be difficult for younger adults to prioritize high-value associated information with a reduction in study time. However, consistent with Middlebrooks, Murayama, et al. (2016), we expected that a reduction in study time would cause younger adults perform similarly to older adults in that they would remember less information overall, but would maintain their ability to selectively focus on high-value visuospatial information.

Method

Participants—The participants in Experiment 1 were 48 younger adults evenly split into two experimental conditions and a group of 24 older adults. The first group of 24 younger adults (16 females) were given 30s presentation time and ranged in age from 19 to 25 years (*M* = 20.79 years, *SD* = 1.59). The second group of 24 younger adults (9 females) were given 15s presentation time and ranged in age from 18 to 25 years (*M* = 20.42 years, *SD* = 1.69). The group of 24 older adults (9 females) ranged in age from 62 to 92 years (*M* = 78.75 years, *SD* = 8.01).

All younger adults were University of California, Los Angeles (UCLA) undergraduate students who participated for course credit. Older adults were recruited from the local community and compensated $10 per hour, plus parking expenses. Younger adults with 30s presentation time had completed an average of 13.50 years of education (*SD* = 1.06), while younger adults with 15s presentation time had completed an average of 13.83 years of education (*SD* = 1.31). Older adults had completed an average of 17.00 years of education (*SD* = 1.44). All older adult participants were in self-reported good health and did not report any significant visual impairment.

Materials—The items used as stimuli in this study were selected from a normed picture database (Snodgrass & Vanderwart, 1980) and were 120 simple black and white line drawings of everyday household items (e.g., key, camera, iron). Each item was approximately 2 × 2 cm in size (although this varied depending on the external shape of the item). From that pool, ten items were randomly selected and placed within a 5 × 5 grid with the constraint that no more than two items be present in any row or column (to avoid arbitrarily forming spatial patterns that may aid memory). On the computer screen, the size of each grid was approximately 15 × 15 cm (with each cell approximately 3 × 3 cm in size). To manipulate the value, each item was randomly assigned a value ranging from 1 (lowest value) to 10 (highest value), which was indicated in the top left portion of the cell in which the item was located (see Figure 1). This process was repeated to form twelve unique grids each with a different set of ten items. In order to avoid testing effects, the values, locations, and grid numbers of items were completely randomized. That is, while one participant may have been presented with a key paired with the 10-point value in the top left cell of the fourth grid, that same item could be paired with the 2-point value in the bottom right cell of the ninth grid for a different participant. As such, each participant was presented with a different set of 12 completely randomized grids.

Procedure—The procedure used in this study was based upon methodologies used in prior experiments investigating VDR (e.g., Castel et al., 2002; Hayes et al., 2013; Robison & Unsworth, 2017) and visuospatial memory (e.g., Chalfonte & Johnson, 1996; Thomas et al., 2012). Participants were instructed that they would be shown a grid with various items placed throughout the grid's cells and to remember the location of the items for a later test. They were then instructed that the items presented within the grid would differ in value, ranging from 1 (lowest value) to 10 (highest value) indicated by a number in the top left corner of the cell and that their goal would be to maximize their score (a summation of the points associated with a correctly remembered item). Importantly, in this experiment, items were presented sequentially. Younger adults in the 30s presentation time group were shown each item for 3s (totaling 30s for the 10 presented items), while younger adults in the 15s presentation time group were shown each item for 1.5s (totaling 15s). Older adults had equivalent study time to the first younger adults group (i.e., each item for 3s).

After viewing the grid, participants were shown a brief visual mask and then a blank 5 × 5 grid with the previously presented items in a row underneath. Participants were instructed to replace the items in their previously viewed locations using the computer mouse (prior to this task, older adults reported they could use the mouse comfortably). If unsure about an item's location, participants were instructed to guess, as their score would not be penalized for misplaced items. There was no time limit for participants during test. After participants placed all 10 items, they were given feedback both on their total score (out of 55 possible points per grid) and the percentage of the total points they received. Participants were able to review their feedback for however long they pleased and were instructed to click a button that would advance them to the next grid at a time of their choosing. After choosing to advance, the subsequent trial would commence with participants immediately shown the new grid to study. Participants then repeated this procedure for all 12 grids. All materials and procedures used in the current study were approved by the UCLA Institutional Review Board.

Results

Overall memory performance—In order to examine age-related differences in memory performance regardless of item value, we conducted a 3 (Group: younger adults with 30s, younger adults with 15s, older adults) × 12 (Grid number: 1, 2, …, 12) repeated-measures analysis of variance (ANOVA) on the proportion of items correctly placed. An item was only counted as correctly placed if participants placed the item in its exact previously viewed cell of the grid. This analysis revealed a significant main effect of group, $F(2, 69) = 18.36$, $p < .001$, $\eta^2 = .35$. Post-hoc t-tests with a Bonferroni correction revealed that younger adults with 30s ($M = .47$, $SD = .22$) correctly placed a greater proportion of items, as compared to older adults ($M = .26$, $SD = .17$), $t(46) = 6.00$, $p < .001$. Younger adults with 15s ($M = .39$, $SD = .20$) also correctly placed a greater proportion of items than older adults, $t(46) = 3.74$, $p = .001$. There was a marginal difference between younger adults with 30s and younger adults with 15s, $t(46) = 2.26$, $p = .08$. There was no significant main effect of grid number and no significant interaction between group and grid number.

Memory selectivity—Participants may have engaged in strategic control to prioritize item-location pairs in memory to maximize their point total, such as focusing on information of differing point values. As such, we wanted to examine how memory performance differed with regard to item value. Similar to results from previous VDR studies (Castel et al., 2002; Hayes et al., 2013; Robison & Unsworth, 2017), participants who recall a higher proportion of high-value items as compared to low-value items can be seen as being selective towards important information given the goal of the task. By examining the relationship between item value and the probability of its correct placement, we could determine whether the odds of correctly placing an item are affected by its value and whether those odds differ between groups or change with continued task experience.

The binning of items into value groups (e.g., low value items: values 1–3, medium value items: values 4–7, high value items: values 8–10) may not accurately depict participants' use of value-based strategies. Some participants may consider items with values 7+ to be "high value" while others may consider items with values 8+ to be "high value". Thus, the arbitrary binning of items into value groups post-hoc may not sufficiently capture differences in participants' value-directed strategies, as value is not treated as a continuous variable. Rather, the current study uses hierarchical linear modeling (HLM) which accounts for both within- and between-participant differences in strategy use (Raudenbush & Bryk, 2002). This statistical method has been used in numerous prior studies examining age-related differences in strategy use in the VDR paradigm (Castel, Murayama, Friedman, McGillivray, & Link, 2013; Middlebrooks, McGillivray, Murayama, & Castel, 2016; Middlebrooks, Murayama, et al., 2016; Middlebrooks, Murayama, & Castel, 2017).

In order to examine correct item placement as a function of age group, grid number, and item value, a two-level hierarchical linear model (HLM) was used. The probability of correctly placing an item (0 = not correctly placed, 1 = correctly placed; level 1 = items; level 2 = participants) was modeled as a function of item value, grid number, and the interaction between item value and grid number. Item value and grid number were entered into the model as group-mean centered variables (with item value anchored at the mean value of 5.5 and grid number anchored at the mean value of 6.5). Age group (0 = younger adults with 30s, 1 = older adults, 2 = younger adults with 15s) was included as a level-2 predictor. In this analysis, younger adults with 30s were treated as the comparison group, while Condition 1 compared younger adults with 30s to older adults and Condition 2 compared younger adults with 30s to younger adults with 15s.

Figure 2 depicts participants' memory performance as a function of group and item value across grid quartiles, while Table 1 presents the tested model and estimated regression coefficients for all experiments in the current study. Estimated regression coefficients can be interpreted by taking their exponential, Exp(β) (Raudenbush & Bryk, 2002). Exp(β) represents an odds ratio of successful item placement. An Exp(β) value greater than one indicates a positive effect of a predictor, while an Exp(β) value less than one indicates a negative effect of a predictor. Results from Experiment 1 indicated that item value was a significantly positive predictor of correct item placement for younger adults with 30s, $\beta_{10} = 0.10$, $p < .001$, which was not significantly different for the other groups (ps > .74). Thus, for each increase in item value participants were $e^{0.10} = 1.10$ times more likely to successfully place that item in its correct location. Regardless of grid number or group, participants were $e^{0.10*10} = 2.61$ times more likely to correctly place a 10-point item, as compared to a 1-point item. The analysis also revealed that grid number was not a significant predictor of correct item placement for younger adults with 30s, $\beta_{20} = -0.02$, $p = .33$, which again was not significantly different for the other groups (ps > .59), indicating that all participants recalled the same amount of information regardless of item value throughout the task. Finally, results indicated a significantly positive interaction between item value and grid number for younger adults with 30s, $\beta_{30} = 0.01$, $p = .02$, which was not significantly different for the other groups (ps > .66). This indicates that the positive relationship between item value and the probability of correctly placing an item increased with every increase in grid number. Thus, while participants remembered the same amount of information from grid-to-grid, they increased their selectivity towards high-value items.

Bayesian analysis—To reinforce the findings of null effects of value on memory performance obtained between groups in the HLM, we computed Bayes factors using a Bayesian analysis. It is possible that the obtained null effects between younger adults with 30s, older adults, and younger adults with 15s are not reflective of a similar effect of value on participants' memory, but rather indicate inadequate sample size leading to underpowered analyses that are unable to detect the true differences between conditions. Computing Bayes factors allows one to compare the probability of obtaining the results under the null hypothesis (i.e., no difference between groups) with the probability of obtaining the results under the alternative hypothesis (i.e., differences in the effect of value on memory performance between groups) (Jarosz & Wiley, 2014).

Comparing Bayes factors within the HLM framework can be difficult (Lorch & Myers, 1990; Murayama, Sakaki, Yan, & Smith, 2014) and as such, we conducted a simpler two-step procedure that has been used in previous VDR studies (Middlebrooks, Murayama, et al., 2016; Middlebrooks et al., 2017). First, using logistic regression, the proportion of items correctly placed was regressed on item value within each grid for each participant. Then, a 3 (Group: younger adults with 30s, older adults, younger adults with 15s) × 12 (Grids: 1, 2, …, 12) repeated-measures Bayesian ANOVA was conducted on the obtained slopes using default priors. This analysis produced a Bayes Factor_{10} ($BF_{10} = .080$) representing the probability of the data under the alternative, as compared to the null hypothesis. The obtained BF_{10} indicates that the data are 1/.080 = 12.50 times more likely to result from the null model versus the alternative. As detailed by Kass and Raftery (1995), a BF_{10} of this magnitude represents "strong" evidence that the obtained results are indicative of a true null effect. Thus, the lack of difference between younger adults (with 30s and 15s) and older adults likely reflects a similar effect of value on memory performance for these groups.

Spatial resolution—An advantage of the design used in the current study is the ability to not only investigate participants' memory for information that they correctly remembered, but also examine participants' spatial resolution (i.e., not only if a participant misplaced an item, but the magnitude of that error) by examining the pattern of errors made by participants and whether these errors varied as a function of group, value, or grid number. In other words, the usage of items within grids as the stimuli in this task allowed us to analyze the distance between a participants' erroneous placement of an item and the item's previously presented location. This type of systematic analysis has not been possible in previous VDR studies using verbal materials such as unrelated words pairs, as determining the distance between an incorrectly provided word and the correct target word proves to be quantitatively difficult (e.g., when cued with *icebox*-__________, is the incorrect answer of *hippopotamus* or *rhinoceros* closer to the correct answer *elephant*?). In these studies, incorrect responses largely remain unanalyzed. By calculating a spatial relocation error score for each incorrectly placed item, we were able to analyze this large section of the data to further inform our findings.

Spatial relocation error was computed in the following manner. For each incorrectly placed item, the coordinates of the erroneous placement were compared to the coordinates of item's previously presented location. An illustration of potential spatial relocation error scores for a given item is depicted in Figure 3. In the context of the 5 × 5 grids used in the current study, coordinates were of the form (row, column) and ranged from (1, 1) indicating the cell in the top left corner of the grid to (5, 5) indicating the cell in the bottom right corner. Row and column differences were calculated by subtracting the incorrect row value from the correct row value and the incorrect column value from the correct column value. The absolute value of the row difference and column difference scores were calculated and the spatial relocation error score was determined by the larger of these two values. Essentially, the spatial relocation error score represents the minimum number of "steps" (either vertical, horizontal, or diagonal) between the incorrect and correct placement of an item. Dependent upon an item's previously presented location, the distance score could range from 1 (directly adjacent to the correct cell) to 4 (four steps away from the correct cell). While certain locations had a maximum spatial relocation error of 3 (e.g., a cell in the center of the grid) and others a maximum of 4 (e.g., a cell in the corner of a grid), these differences were likely evenly distributed across item value and grid number due to the random assignment of value to items and random placement of items within grids for each participant. This spatial relocation error score was used as the dependent variable in the following analyses.

First, we examined spatial relocation error across grids and between conditions, without regard to item value. Similar to analyses conducted on SI scores, we averaged across grid quartiles (Grids 1–3, 4–6, etc.) in order to minimize missing data for participants who correctly placed all 10 items for a grid resulting in no spatial relocation error value for that particular grid. After collapsing into grid quartiles, no participants had missing data and all were included in the following analysis. We conducted a 3 (Group: younger adults with 30s, younger adults with 15s, older adults) × 4 (Grid numbers: 1–3, 4–6, 7–9, 10–12) repeated-measures ANOVA on spatial relocation error and found a main effect of group, $F(2, 69) = 5.13$, $p = .01$, $\eta^2 = .13$. Post-hoc comparisons with a Bonferroni correction indicated that spatial relocation error for younger adults with 30s ($M = 1.88$, $SD = 0.34$) was significantly smaller than older adults ($M = 2.05$, $SD = 0.28$), $t(46) = 3.01$, $p = .01$, and marginally smaller than younger adults with 15s ($M = 2.02$, $SD = 0.29$), $t(46) = 2.46$, $p = .05$. There was no difference between the spatial relocation error of older adults and younger adults with 15s. Additionally, there was no main effect of grid number and no interaction between group and grid number.

To examine spatial relocation error with regard to item value between groups, an HLM framework similar to the previous one conducted on memory performance was applied to participants' spatial relocation error scores. Spatial relocation error as a function of age group and item value in Experiment 1 is depicted in Figure 4. The same two-level HLM (level 1 = items, level 2 = participants) used previously was conducted using spatial relocation error as the outcome variable (1 = directly adjacent to correct cell, 4 = four steps from correct cell). In this analysis, older adults were coded as the comparison group, Condition 1 compared older adults and younger adults with 30s adults, and Condition 2 compared older adults with younger adults with 15s. The resulting estimated regression coefficients and variance components are shown in Table 2. Results indicated that value was a significantly negative predictor of spatial relocation error for older adults, $\beta_{10} = -0.03$, $p < .001$, which was significantly different between older adults and younger adults with 30s, $\beta_{11} = 0.04$, $p < .001$, and marginally different for younger adults with 15s, $\beta_{11} = 0.02$, $p = .07$. Rerunning the analysis with younger adults with 30s as the comparison group confirmed that value was not a significant predictor of spatial relocation error for that group, $\beta_{10} = 0.01$, $p = 0.47$, or for younger adults with 15s, $\beta_{11} = -0.02$, $p = .15$. Returning to the HLM with older adults as the comparison group, grid number was a marginal positive predictor of spatial relocation error for older adults, $\beta_{20} = 0.01$, $p = .08$, which was consistent for the other groups ($ps > .35$). Further, there was no interaction between item value and grid number for older adults, $\beta_{30} = -0.002$, $p = .51$, which was also consistent for the other groups ($ps > .53$). Taken together, these results suggest that the higher the item value, the smaller the spatial relocation error for older adults, while younger adults' (with both 30s and 15s) spatial relocation error did not vary systematically as a function of item value.

Discussion

For sequentially presented information, younger adults' overall associative memory for item-location pairs was consistently more accurate than older adults and younger adults with reduced study time as reflected by a greater proportion of items correctly placed and smaller spatial relocation error for incorrectly placed items throughout the experiment. Interestingly, results obtained in SI and HLM analyses indicated that all three groups of participants became more selective by correctly placing more a higher proportion of high-value information with continued task experience. When examining spatial resolution, only older adults' spatial displacement errors were influenced by value, with high-value items being placed closer to the target location than low-value items throughout the task. This was not the case for either group of younger adults, whose spatial displacement errors exhibited a more random pattern during throughout the task.

Experiment 2

As demonstrated in Experiment 1, when items were presented sequentially in a visuospatial environment, participants may not immediately engage in effective strategic control processes during encoding and require task experience to reach peak selectivity. The goal of Experiment 2, then, was to determine whether the simultaneous presentation of items would result in differences in overall memory and selectivity. Given that all associated information would be available to participants for the entire presentation time, would participants more effectively select a subset to study, and would older adults benefit more under these conditions? And if so, how might selectivity change with increased task experience? The sequential presentation of information may inhibit participants from allocating study time towards items of their choice, which may limit their ability to engage in strategic control processes during encoding (Robison & Unsworth, 2017). On the other hand, when information is presented simultaneously, participants are able to voluntarily allocate study time, which may enable more effective strategy use. We wanted to examine whether this would be the case in a more cognitively demanding visuospatial binding task. Finally, similar to Experiment 1, we wanted to determine whether younger adults' pattern of selectivity would be altered when study time was reduced.

Method

Participants—Experiment 2 was conducted with a new group of 48 younger adults evenly split into two experimental conditions and a new group of older adults. Again, the first group of 24 younger adults (17 females) were given 30s presentation time and ranged in age from 18 to 25 years ($M = 20.17$ years, $SD_{age} = 1.66$). The second group of 24 younger adults (15 females) were given 15s presentation time and ranged in age from 18 to 25 years ($M = 21.75$ years, $SD = 1.56$). The group of 24 older adults (11 females) ranged in age from 64 to 90 years ($M = 77.29$ years, $SD = 8.14$). All younger adults were UCLA undergraduate students who participated for course credit. Older adults were recruited from the local community and were compensated $10 per hour, plus parking expenses. The younger adults with 30s presentation time had completed an average of 13.50 years of education ($SD = 1.35$), while the younger adults with 15s had completed an average of 14 years of education ($SD = 0.83$). The older adults had completed an average of 16.25 years of education ($SD = 1.70$). All older adult participants were in self-reported good health and did not report any significant visual impairments. None of the participants from Experiment 1 participated in Experiment 2.

Materials—The materials used in Experiment 2 were identical to those used in Experiment 1 (i.e., 120 simple black-and-white line drawings of everyday household items). As in the previous experiment, 10 items were randomly selected, paired with point values 1–10, and placed within a 5 × 5 grid to form the 12 unique grids used as the stimuli in this experiment.

Procedure—The procedures in this experiment were identical to those in Experiment 1, except for the presentation format of the items. As in the previous experiment, participants were instructed that they would be studying items paired with point values within a grid and their goal was to maximize their point score. In this experiment, however, participants were instructed that they would see all 10 items within the grid at the same time. The first group of younger adults studied the grid for 30s, while the second group of younger adults studied the grid for 15s. All older adults studied the grid for 30s. After the allotted study time had elapsed, participants were shown a brief visual mask and asked to place items in their previously viewed locations. Participants were then given feedback on their performance and repeated the process for all 12 grids.

Results

Overall memory performance—To examine overall memory performance when items were presented simultaneously, we conducted a 3 (Group: younger adults with 30s, younger adults with 15s, older adults) × 12 (Grid number: 1, 2, …, 12) repeated-measures ANOVA on the proportion of items correctly placed overall (out of 10 items per grid). This analysis revealed a main effect of group, $F(2, 69) = 16.49$, $p < .001$, $\eta^2 = .32$. Post-hoc comparisons with a Bonferroni correction revealed that younger adults with 30s ($M = .66$, $SD = .26$) correctly placed a significantly higher proportion of items, as compared to older adults ($M = .40$, $SD = .23$), $t(46) = 5.73$, $p < .001$, and as compared to younger adults with 15s ($M = .51$, $SD = .25$), $t(46) = 3.26$, $p = .01$. Further, there was a marginal difference between younger adults with 15s and older adults, $t(46) = 2.46$, $p = .05$. There was no main effect of grid number and no interaction between group and grid number.

Memory selectivity—Participants' memory performance as a function of age group and item value in Experiment 2 is depicted in Figure 3. The same two-level HLM analysis (level 1 = items, level 2 = participants) conducted in Experiment 1 was applied to the new sample collected in this experiment with younger adults with 30s as the comparison group, Condition 1 comparing younger adults with 30s with older adults, and Condition 2 comparing younger adults with 30s with younger adults with 15s. The analysis revealed that item value was a significantly positive predictor of correct item placement for younger adults with 30s, $\beta_{10} = 0.08$, $p = .02$, which was not significantly different for the other groups (ps > .14). Thus, with each increase in value, participants were $e^{0.08} = 1.09$ times more likely to correctly place that item, regardless of grid number or group. Similarly, participants were $e^{0.08*10} = 2.31$ times more likely to correctly place a 10-point item, as compared to a 1-point item, regardless of grid number or group. Further, there was no effect of grid number for younger adults with 30s, $\beta_{20} = 0.0001$, $p = .99$, which was consistent for the other groups (ps > .67). This indicates that participants correctly placed the same proportion of items (within each group and irrespective of item value) across grids. Notably, in contrast to Experiment 1, there was not a significant interaction between item value and grid number for younger adults with 30s, $\beta_{30} = 0.004$, $p = .31$, which again was consistent for the other groups (ps > .47).

Bayesian analysis—Similar to Experiment 1, Bayes factors were calculated using a Bayesian analysis to investigate the lack of differences in the effect of value on memory performance between groups. The same two-step process (e.g., logistic regression to obtain slopes for each participant on each grid and a 3 (Group) × 12 (Grid) repeated-measures Bayesian ANOVA using default priors) was applied to the data collected in Experiment 2 and a BF_{10} of .083 was obtained. This indicates that the data are 1/.083 = 12.05 times more likely to be consistent with the null model as compared to the alternative model. Again, this provides "strong" evidence that the lack of group differences is a result of a similar effect of value on memory performance (Kass & Raftery, 1995) and not due to inadequate sample size.

Spatial resolution—We also examined participants' spatial resolution by examining the pattern of errors produced by participants using spatial relocation error as a dependent variable. After averaging into grid quartiles, six participants were excluded from the following analysis due to missing data on at least one grid quartile (indicating that those participants correctly placed all 10 items for three consecutive grids). These participants were the same as the ones excluded in the above SI analysis for Experiment 2 (after exclusion, $n_{younger\ 30s} = 20$, $n_{younger\ 15s} = 23$ and $n_{older} = 23$). We conducted a 3 (Group: younger adults with 30s, younger adults with 15s, older adults) × 4 (Grid numbers: 1–3, 4–6, 7–9, 10–12) repeated-measures ANOVA on spatial relocation error and found a main effect of group, $F(2, 63) = 4.07$, $p = .02$, $\eta^2 = .11$. Post-hoc comparisons with a Bonferroni correction indicated that younger adults with 30s ($M = 1.61$, $SD = 0.46$) had significantly smaller spatial relocation error scores than older adults ($M = 1.83$, $SD = 0.32$), $t(41) = 2.58$, $p = .04$, and marginally smaller spatial relocation error scores than younger adults with 15s ($M = 1.82$, $SD = 0.38$), $t(41) = 2.41$, $p = .06$. There was no difference in spatial relocation error scores between older adults and younger adults with 15s. Additionally, there was no main effect of grid number and no interaction between group and grid number.

Again, to examine spatial relocation error with regard to item value between groups, an HLM was applied to the relocation error data obtained in Experiment 2. No participants were excluded for this analysis. Spatial relocation error as a function of age group and item value in Experiment 2 is depicted in Figure 6. The coding of groups followed the same pattern as Experiment 1 (comparison = older adults, Condition 1 = older adults v. younger adults with 30s, Condition 2 = older adults v. younger adults with 15s). Results indicated that item value was a significantly negative predictor of spatial relocation error for older adults, $\beta_{10} = -0.04$, $p < .001$, which was consistent for the other groups (ps > .25). Grid number was not a significant predictor of spatial relocation error for older adults, $\beta_{20} = -0.01$, $p = .36$, which was not significantly different between older adults and younger adults with 30s, $\beta_{21} = 0.01$, $p = .28$. There was a marginal difference of the effect of grid number between older adults and younger adults with 15s, $\beta_{22} = 0.02$, $p = .06$. Rerunning the analysis with younger adults with 15s as the comparison group indicated that grid number was only a marginal positive predictor of spatial relocation error for that group, $\beta_{20} = 0.01$, $p = .07$. These results demonstrate that the higher the item value, the closer participants' placement of items was to the target location for simultaneously presented information.

Discussion

For simultaneously presented information, we again found that younger adults' overall memory for item-location associations was more accurate than that of older adults and younger adults with 15s, both in terms of correctly placed information and spatial displacement errors. However, SI and HLM results indicated that all three groups of participants maintained a similar level of selectivity throughout the task. Further, with regard to incorrectly placed items, all three groups exhibited a negative relationship between item value and spatial displacement errors such that participants placed higher value items closer to the target location than lower value items. This deviates from the sequentially presented information in Experiment 1 in which only older adults spatial relocation errors were influenced by item value.

General Discussion

Previously established age-related impairments in visuospatial memory are reflective of an associative memory deficit that occurs with advancing age (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000) and may be due to the effortful allocation of attention required to bind the identity and location features of an object during encoding (Treisman & Gelade, 1980; Treisman & Sato, 1990). The goal of these experiments was to determine whether age-related deficits in visuospatial binding could be influenced by younger and older adults' use of strategic attentional control processes to focus on and later remember high-value information. Further, we were interested in how varying presentation formats may differentially influence these value-based encoding strategies by making their usage more demanding or strategical in nature. In both experiments, younger adults remembered more information overall than older adults across the task when matched on study time. With regard to information that was misremembered, younger adults placed items closer to the target location than older adults. These findings support prior research demonstrating significant age-related deficits in visuospatial memory related to an impaired ability to bind visual and spatial features of items due to an associative deficit (Naveh-Benjamin, 2000; Park et al., 2002; Thomas et al., 2012).

More interesting differences arose when examining memory based on the value of information. As previously discussed, research using verbal versions of the VDR task has shown that older adults are able to selectively focus on high-value information at the expense of competing low-value information, often remembering as much of the high-value information as their younger adult counterparts (Castel et al., 2002). Importantly, these value-based strategies are dependent upon the strategic allocation of attention at encoding (i.e., allocating attention towards high-value and away from low-value information). Consistent with previous VDR findings (e.g., Castel et al., 2002; Hayes et al., 2013; Robison & Unsworth, 2017), we found that increasing value had a significantly positive effect on the probability of correct placement for both younger and older adults in both experiments. That is, participants in all experiments were more likely to correctly place high-value information (i.e., those 10-, 9-, and 8-point items), as compared to medium- or low-value information. Thus, overall, participants appeared to be using strategic attentional control processes in these tasks, as both younger and older adults were able to successfully remember associations between high-value items and their locations. Relatedly, Ariel, Price, and Hertzog (2015) demonstrated older adults' ability to use value-based strategies to aid associative memory for word pairs. However, they also found age-related memory impairments for all associated information and perhaps even larger differences for associated high-value information. Our results are generally consistent with these findings – while both younger and older adults were able to selectively study and later remember high-value information, age-related memory differences were still present for information of all values.

There are two likely explanations for these impairments in the current study. Firstly, unlike word pairs, item-location associations are not easily verbally rehearsed. As has been well-documented, elaborative rehearsal leads to better subsequent memory performance (e.g., Craik & Watkins, 1973) and prior research has shown that older adults tend to re-rehearse high-value information after study in an attempt to better encode that information for later test (Castel et al., 2013). However, in the context of the current task, it may be difficult, or even impossible, for participants to elaborately rehearse the presented visuospatial associations. For example, how would one rehearse that the kettle is at the intersection of the first row and the second column? Thus, limiting this ability to rehearse associations may have disproportionately affected older adults' value-based strategy use, which in turn may have inhibited their ability to eliminate age-related memory differences for high-value information, as found in prior VDR research (Castel et al., 2002). Secondly, the binding of visual and spatial features of an item presents a unique challenge. Associating item identity and location information likely involves the use of serial and effortful allocation of attention (Treisman & Gelade, 1980; Treisman & Sato, 1990). For older adults, this may have been particularly difficult given their diminished cognitive resources (Craik & Byrd, 1982), which would limit their ability to engage in strategic attentional control processes. So, while older adults were equally as selective as their younger adult counterparts, age-related differences in memory for item-location associations still emerged likely due to these two factors.

Further, the results of the current experiments support prior work demonstrating that participants may be less effective in carrying out agendas related to task goals when information is encountered in a sequential fashion (Ariel et al., 2009; Dunlosky & Thiede, 2004). In the current task, when information was presented sequentially, participants became more selective as task experience increased. In this presentation format, participants were forced to maintain the association between the item and its spatial location in visuospatial working memory while concurrently making judgments on whether to attempt to encode newly presented items based on their point value. Given the strain placed on attentional resources by both sequentially presented information and the binding of item identity and location information, it may have been more difficult for both younger and older participants to effectively allocate attention towards high-value information. After continued task experience, however, participants may have been motivated to try different strategies in order to increase their point total, leading to more effective attentional control later in the task. In contrast, when information was presented simultaneously, participants' pattern of selectivity did not change across the task. Participants were able to strategically allocate attention towards high-value item-location pairs with little task experience. All information was available to participants for the duration of the study period. As such, participants may be better able select a subset of items to study and more efficiently allocate study time and return multiple times to study items that they deemed important. There was also no maintenance of information required throughout the study phase as all information was available to participants for the duration of the study period. These factors likely account for this difference in selectivity across task experience between the different presentation formats. It is almost important to note that these patterns of selectivity were consistent between younger nad older adults in each experiment. This may not have been the case, as the increased demands on attentional and working memory resources in the sequential presentation may have disproportionately affected older adults' ability to remember visuospatial associations. As such, these results lend further support towards older adults' preserved ability to engage in strategic attentional control processes in light of resource demanding tasks like binding visual and spatial features and engaging in value-based strategies for sequentially presented information.

Further, results from our spatial resolution analyses demonstrate that participants relied on gist-based visuospatial information in the absence of any explicit item-location recall and that only older adults' gist-based visuospatial memory was stronger for high- relative to low-value information regardless of presentation format. In contrast, younger adults at both presentation rates only demonstrated this effect of value on spatial resolution when information was presented simultaneously. Younger adults, who may not use gist memory to the same extent as older adults (e.g., Brainerd & Reyna, 2001; Koutstaal, 2006; Reder et al., 1986), may have only exhibited value effects on spatial resolution when encoding conditions were less cognitively demanding. Under more demanding encoding conditions, younger adults may have relied more on verbatim item-location memory which would result in the more random pattern of spatial resolution that were observed in the current study. This novel finding adds further support to notion that strategic encoding processes are most efficiently implemented by younger adults when information is presented simultaneously, while older adults may voluntarily engage, or need to engage, in such processes regardless of presentation format.

It is also important to note that participants appeared to recall more information overall in the simultaneous condition ($M_{younger30s} = 0.66$, $M_{younger15s} = 0.51$, $M_{older} = 0.40$, as compared to the sequential condition ($M_{younger30s} = 0.47$, $M_{younger15s} = 0.39$, $M_{older} = 0.26$), at least numerically. No analyses were conducted between experiments to determine whether these differences were statistically significant because participants were not randomly assigned to presentation format condition. One can imagine that if less information is recalled overall, participants may selectively remember more high-value information (as is the case when comparing younger adults' greater memory capacity to that of older adults). However, a decrease in overall associative memory accuracy for sequentially-presented information did not lead to greater selectivity, as compared to simultaneously-presented information – rather it seemed to hinder participants' ability to study selectively, which they overcame with increased task experience. So, both overall recall and ability to use strategies related to task goals appeared to be impaired when information was encountered sequentially, as compared to simultaneously. However, we approach any direct comparison between presentation formats with caution given the design of the current study. Future research should directly compare the effects of presentation format on the execution of value-based study strategies in the context of a cognitively demanding visuospatial binding task.

Finally, while prior research investigating VDR in younger adults has shown that a reduction in study time may reduce participants' overall memory performance, there seems to be no effect on participants' ability to selectively remember high-value information (Middlebrooks, Murayama, et al., 2016). In the current study, a similar pattern of results was found when presentation time was reduced for younger adults. Although they remembered less visuospatial information overall as compared to younger adults with 30s study time, younger adults' pattern of selectivity was not significantly different with shorter encoding time, regardless of presentation format. Thus, while reduced encoding time limited the amount of information younger participants could later remember, it did not affect their ability to selectively allocate study-time towards and later remember high-value information.

One limitation of the current study relates to the manner in which participants' memory was tested. By having participants' place items in their previously viewed locations, participants' associative memory for the item-location pairs was queried, as we were particularly interested in the potential effects of information importance under attentionally-demanding conditions like visuospatial binding. However, we did not investigate participants' component memory for visual (i.e., the presence or absence of a particular item in any location within the grid) or spatial (i.e., the presence or absence of any item in a particular location within the grid) memory individually. As such, it is possible that the observed effects of value may be due to a change in component, rather than associative memory. Given the current experimental design, we cannot claim that value-based study strategies exclusively or more drastically influence associative, as compared to component memory. That said, for participants to correctly place a previously viewed item, they were required to successfully remember the item-location association. As such, we feel confident that value did indeed influence visuospatial binding. As to whether this influence was through direct (i.e., an exclusive memory boost to high-value item-location pairs) or indirect (i.e., a boost to individual visual or spatial component memory leading to better overall memory for high-value item-location pairs) means, the results remain inconclusive. An interesting line of future should directly compare the effects of value on visual, spatial, and binding memory to more specifically identify the source of the observed value effects in the current study.

Future research should also explore the effect of the vividness of context or the use of schemas on visuospatial binding ability. Prior studies have shown that older adults may show item and spatial memory benefits when the presented visuospatial context has greater visual complexity (e.g., a three-dimensional model of a bedroom is more distinctive than a two-dimensional map of the same room; Sharps & Gollin, 1986), although other research only found this benefit for spatial memory (Park, Cherry, Smith, & Lafronza, 1990). Increasing the visuospatial distinctiveness may also provide more schematic support for older adults (e.g., knowing that the fork belongs somewhere in the kitchen). Prior research has shown that associative memory may be improved when older adults can rely on prior knowledge and schemas (Castel, 2005; Hess & Slaughter, 1990). When including the added factor of value, one may expect to find similar, or even enhanced, effects on visuospatial binding. For example, older adults may be better at remembering where their eyeglasses (commonly a high-value item in daily life) are located in a room, as compared to where their pen (commonly a low-value item) is located, especially when they are able to rely on schematic support. While the present study used a rather sparse spatial environment, this allowed for a more precise examination of how strategic encoding factors can influence memory in the absence of other schematic factors that could support, or interfere with, the binding of items and locations in visuospatial memory.

Conclusion

The current study sought to determine whether age-related deficits in visuospatial binding ability could be alleviated by engaging in strategic control processes and whether the ability to implement these strategies would vary given the presentation format and the amount of task experience. Despite overall visuospatial associative memory deficits for older adults, all participants were able to engage in strategic control processes after sufficient task experience when information was presented sequentially, and from the beginning of the task when information was presented simultaneously. Older adults, who may have reduced attentional and working memory resources, were still able to selectively remember associative information in the face of resource demanding tasks like visuospatial binding and remembering sequentially presented information. Reducing presentation time for younger adults led to lower overall memory performance, but did not affect the pattern of selectivity. Further, the introduction of novel spatial resolution analyses extended older adults’ reliance on gist-based memory to the visuospatial domain, while younger adults gist-based visuospatial memory was only influenced by value under less demanding encoding conditions. Overall, while the current study finds further support for age-related deficits in the binding of visual and spatial information, it also provides evidence that older adults are able to use effective value-based strategies to remember the most important associated information in a visuospatial context.

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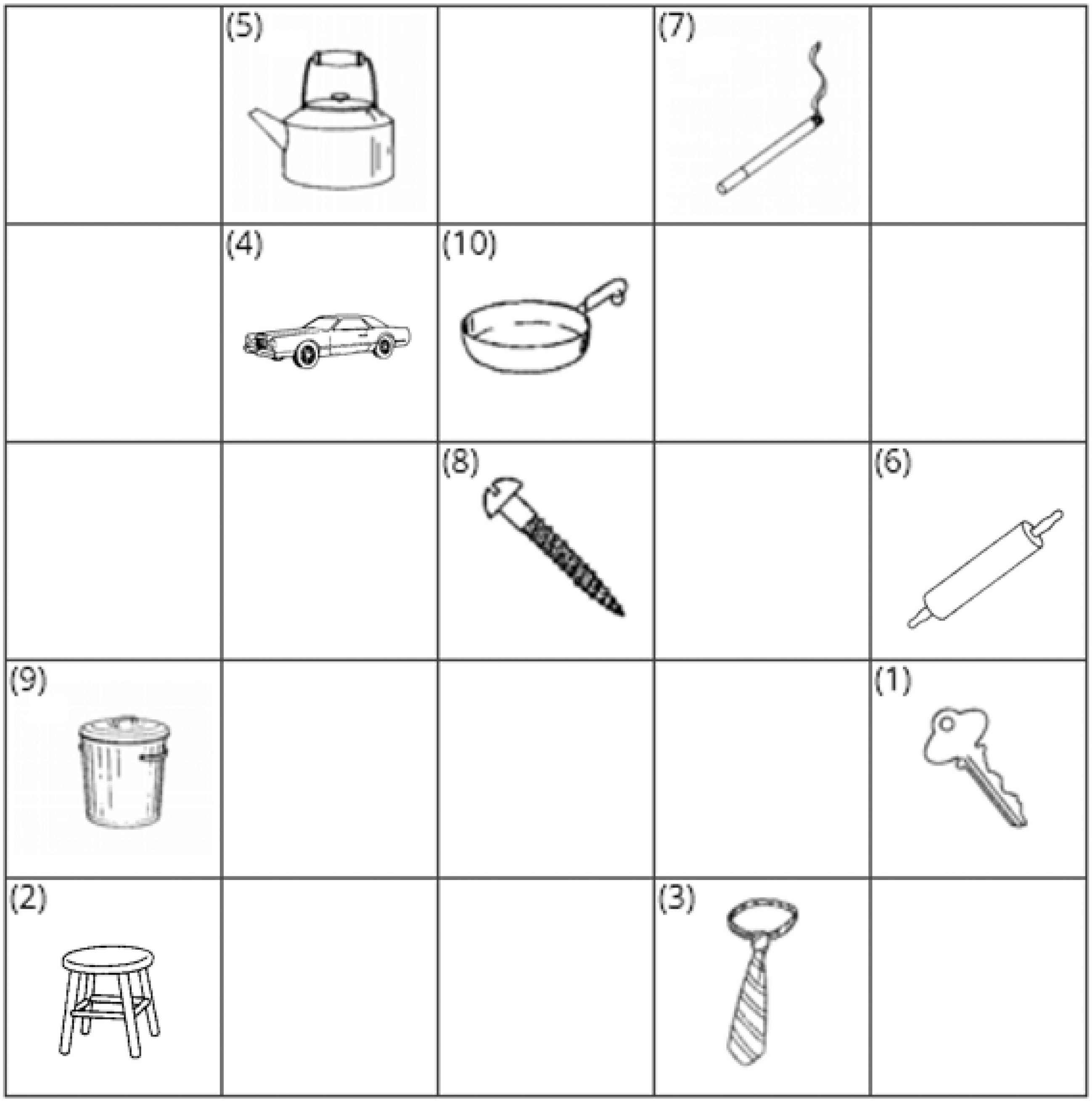

Figure 1.

An example of a grid that participants may have been presented with during the study phase. Ten household items were paired with point values 1–10 indicated in the top left corner of each cell. In Experiment 1 items were presented sequentially and in Experiment 2 items were presented simultaneously as seen in this figure.

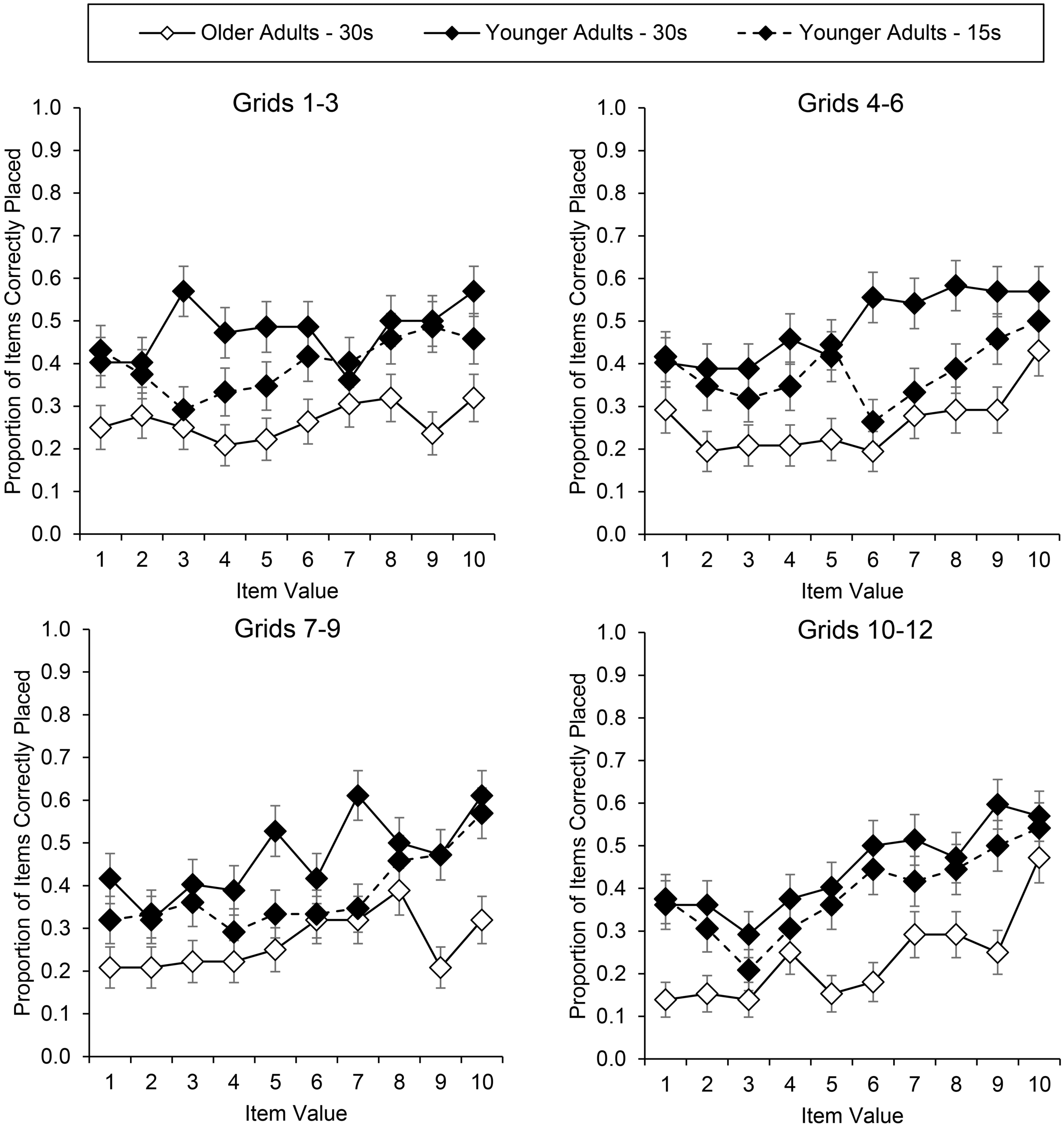

Figure 2.

The proportion of items correctly placed as a function of item value when presented sequentially in Experiments 1 displayed in grid quartiles. Error bars represent ±1 standard error.

3	3	3	3	4
2	2	2	3	4
1	1	2	3	4
	1	2	3	4
1	1	2	3	4

Figure 3.

An example of spatial relocation error scores relative to an item’s correct location. Spatial relocation error represents the number of “steps” from an incorrectly placed item to the previously presented location. Depending on the target location, the spatial relocation error score ranged from 1 (*directly adjacent to the previously presented location*) to 4 (*distance of four steps from correct placement*). Lighter shades indicate a misplaced item closer to the target cell resulting in a small spatial relocation error score. Darker shades indicate a misplaced item farther from the target cell resulting in a large spatial relocation error score.

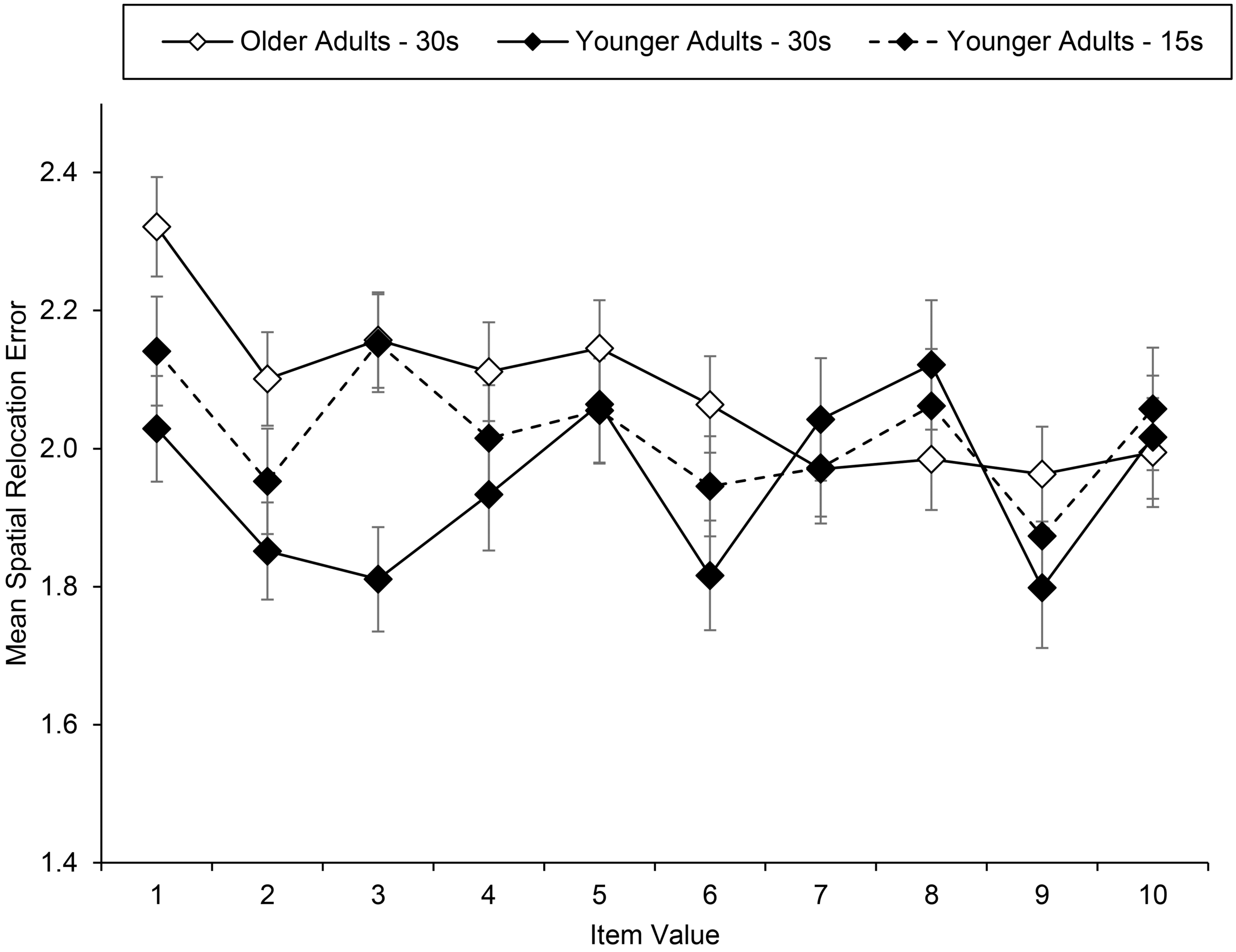

Figure 4.

Mean spatial relocation error as a function of item value and group averaged across grids for sequentially presented item-location associations in Experiment 1. Error bars represent ±1 standard error.

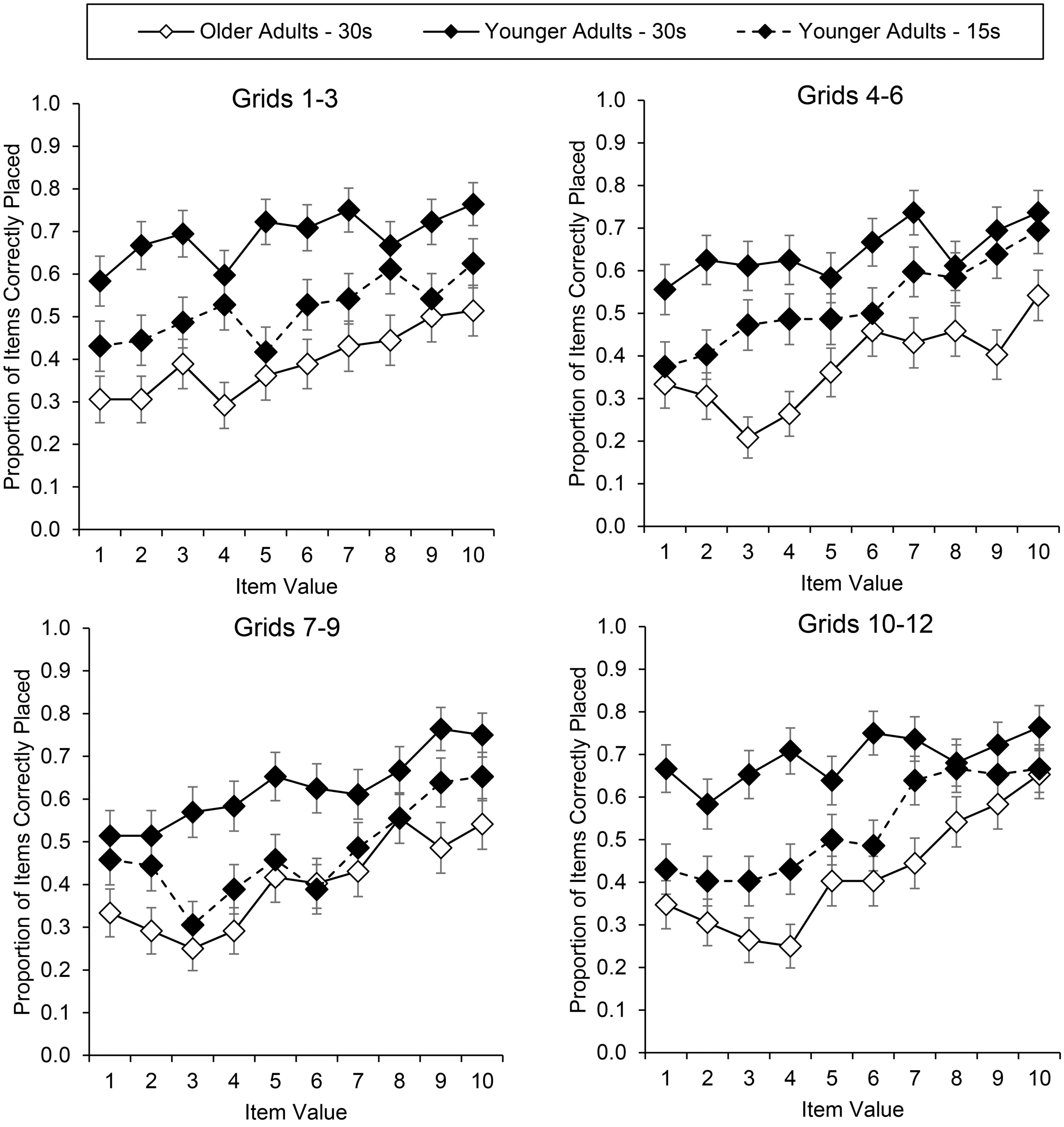

Figure 5.

The proportion of items correctly placed as a function of item value when presented simultaneously in Experiment 2. Error bars represent ±1 standard error.

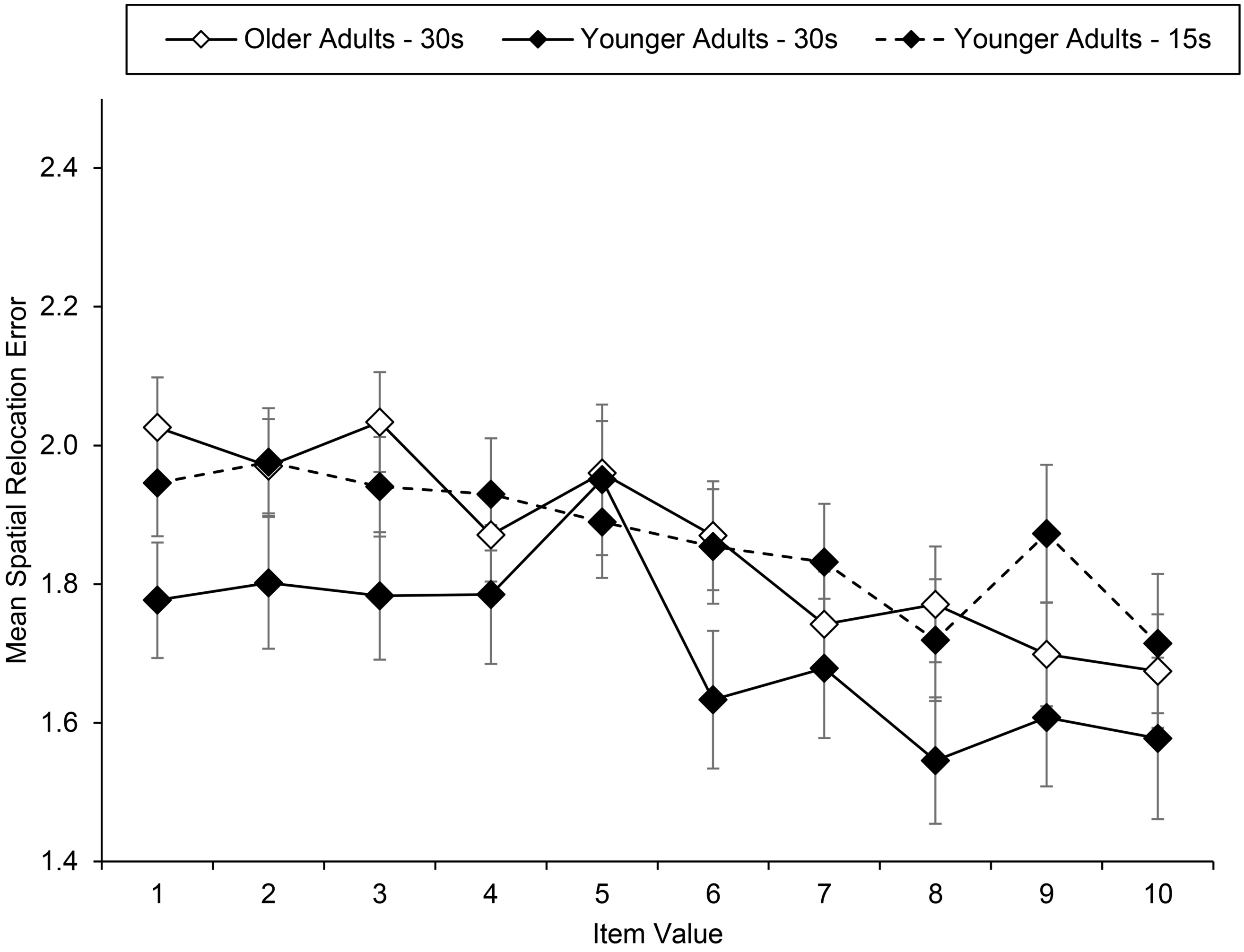

Figure 6.

Mean spatial relocation error as a function of item value and group averaged across grids for simultaneously presented item-location associations in Experiment 2. Error bars represent ±1 standard error.

Table 1

Two-Level Hierarchical Generalized Linear Model of Memory Performance Predicted by Item Value, Grid Number, and Participant Group

Fixed Effects	**Exp. 1 Coefficients**	**Exp. 2 Coefficients**
Intercept (β_{00})	–0.15	0.74[***]
Predictors of intercept		
Condition 1: Younger adults 30s v. Older adults 30s (β_{01})	–1.03[***]	–1.22[***]
Condition 2: Younger adults 30s v. Younger adults 15s (β_{02})	–0.34[*]	–0.69[**]
Value (β_{10})	0.10[***]	0.08[*]
Predictors of Value		
Cond1: YA 30s v. OA 30s (β_{11})	–0.001	0.07
Cond2: YA 30s v. YA 15s (β_{12})	–0.01	0.05
Grid number (β_{20})	–0.02	0.0001
Predictors of Grid number		
Cond1: YA 30s v. OA 30s (β_{21})	–0.01	0.01
Cond2: YA 30s v. YA 15s (β_{22})	0.01	0.001
Value x Grid number (β_{30})	0.01[*]	0.004
Predictors of Value x Grid number		
Cond1: YA 30s v. OA 30s (β_{31})	.003	0.003
Cond2: YA 30s v. YA 15s (β_{32})	–.001	0.005
Random Effects	**Exp. 1 Variance**	**Exp. 2 Variance**
Intercept (person-level) (r_0)	0.30[***]	0.59[***]
Value (r_1)	0.01[***]	0.02[***]
Grid Number (r_2)	0.003[***]	0.007[***]
Value x Grid number (r_3)	0.0002[**]	0.0001[*]

Note. In these analyses, correct item placement was coded as 0 (*not correctly placed*) or 1 (*correctly placed*). A logit link function was applied to address the binary dependent variable. Levels 1 models were of the form $\eta_{ij} = \pi_{0j} + \pi_{1j}$ (Value) + π_{2j} (Grid number) + π_{3j} (Value x Grid number). Level 2 models were of the form $\pi_{0\mathrm{j}} = \beta_{00} + \beta_{01}$ (Cond1) + β_{02} (Cond2) + r_{0j}; $\pi_{1j} = \beta_{10} + \beta_{11}$ (Cond1) + β_{12} (Cond2) + r_{1j} $\pi_{2j} = \beta_{20} + \beta_{21}$ (Cond1) + β_{22} (Cond2) + r_{2j}; $\pi_{3j} = \beta_{30} + \beta_{31}$ (Cond1) + β_{32} (Cond2) + r_{3j}.

[*] $p < .05$

[**] $p < .01$

[***] $p < .001$.

Table 2

Two-Level Hierarchical Generalized Linear Model of Spatial Relocation Error Predicted by Item Value, Grid Number, and Participant Group

Fixed Effects	**Exp. 1 Coefficients**	**Exp. 2 Coefficients**
Intercept (β_{00})	2.06***	1.84***
Predictors of intercept		
Condition 1: Older adults 30s v. Younger adults 30s (β_{01})	–0.13*	–0.17*
Condition 2: Older adults 30s v. Younger adults 15s (β_{02})	–0.05	0.02
Value (β_{10})	–0.03***	–0.04**
Predictors of Value		
Cond1: OA 30s v. YA 30s (β_{11})	0.04***	0.02
Cond2: OA 30s v. YA 15s (β_{12})	0.02	0.02
Grid number (β_{20})	0.01	–0.01
Predictors of Grid number		
Cond1: OA 30s v. YA 30s (β_{21})	–0.01	0.01
Cond2: OA 30s v. YA 15s (β_{22})	–0.01	0.02
Value x Grid number (β_{30})	–0.002	0.002
Predictors of Value x Grid number		
Cond1: OA 30s v. YA 30s (β_{31})	–0.002	0.002
Cond2: OA 30s v. YA 15s (β_{32})	0.002	–0.01

Random Effects	**Exp. 1 Variance**	**Exp. 2 Variance**
Intercept (person-level) (r_0)	0.02***	0.03***
Value (r_1)	0.001	0.001*
Grid Number (r_2)	0.001	0.003
Value x Grid number (r_3)	0.00002	0.00001

Note. In these analyses, spatial relocation error was coded on a scale from 1 (*directly adjacent to target location*) to 4 (*distance of four steps from target location*). Levels 1 models were of the form $\eta_{ij} = \pi_{0j} + \pi_{1j}$ (Value) + π_{2j} (Grid number) + π_{3j} (Value x Grid number). Level 2 models were of the form $\pi_{0j} = \beta_{00} + \beta_{01}$ (Cond1) + β_{02} (Cond2) + r_{0j}, $\pi_{1j} = \beta_{10} + \beta_{11}$ (Cond1) + β_{12} (Cond2) + r_{1j} $\pi_{2j} = \beta_{20} + \beta_{21}$ (Cond1) + β_{22} (Cond2) + r_{2j}, $\pi_{3j} = \beta_{30} + \beta_{31}$ (Cond1) + β_{32} (Cond2) + r_{3j}.

[*] $p < .05$

[**] $p < .01$

[***] $p < .001$.