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Metacognitive Monitoring in Visuo-Spatial Working Memory

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Abstract

Age-related research within the domain of spatial working memory has not conclusively determined whether age differences exist. Under some conditions, age-equivalence has been demonstrated for location information. Under other conditions age-equivalence has been demonstrated for identity information. In three experiments we examined these two components, as well as their combination, of visual-spatial working memory (VSWM) in younger and older adults. In addition, we examined metacognitive processes associated with each VSWM component. Results suggest that while age differences exist in both components, older adults performed at the level of younger adults when encoding was equated. Our results also suggest that location information may be less effortfully processed as compared to identity information. These processing differences across VSWM components may contribute to the greater observed difficulty older adults have in monitoring location memory performance as compared to younger adults. Overall, the present study is the first to demonstrate both age-deficits and age-equivalence in metacognitive prediction accuracy within a working memory paradigm.

According to the working memory model first proposed by Baddeley and Hitch (1974), verbal and visuospatial information are maintained via separate working memory components, the articulatory loop and the visuospatial sketchpad, respectively. Baddeley and Hitch (1994) suggested that the sketchpad itself consists of two dissociable components, one for maintaining object features and the other for maintaining spatial locations (see also, Logie, 1995). The present research examines the VSWM components in younger and older adults. The primary goal of the present research was to test whether age similarly affects object memory and location memory. In addition, we investigated whether older and younger adults could effectively metacognitively monitor the two VSWM components.

Visual Spatial Working Memory

Several studies support the conclusion that two dissociable components comprise VSWM. As evidence for this dissociation, in dual-task paradigms, participants demonstrate task-specific interference. Specifically, Logie and Marchetti (1991) presented participants with either an array of color shades or a series of squares shown sequentially in different random locations. During a retention interval, participants watched a blank screen, performed a spatial tapping task, or viewed irrelevant line drawings of objects. Interpolated tapping impaired memory for the location series, whereas line drawings did not. In contrast, memory for color shades was impaired only by line drawings. Della et al., (1999) reported similar results using the Visual Patterns Task (VPT), which involves remembering an abstract matrix array presented as a single pattern, and a version of the Corsi Blocks Task, which involves memory for a sequence of object movements in an array.

As two dissociable components comprise VSWM, researchers have examined whether age similarly affects each component. Unfortunately, this examination has yielded conflicting findings. Using 5 x 5 grids containing several letters, Schear and Nebes (1980) compared item/object identity memory with spatial location memory, and found similar age-related deficits for both memory types. Likewise, using several analytic procedures, Salthouse (1995) demonstrated that age related effects in VSWM were not selective. Alternatively, when using unfamiliar objects (Arabic alphabet) to test VSWM, results indicated age-deficits for object identity memory, and age-equivalence for location memory (Hartley, 2001). Finally, research done by Hale and colleagues, demonstrated greater age-deficits in location memory as compared to object memory (Chen, Hale, & Myerson, 2003; Jenkins, Myerson, Joerding, & Hale, 2000).

In all of these studies, participants saw objects in a matrix context. However, numerous methodological differences exist among these studies, potentially influencing the age-related findings. As one example, several studies employed secondary tasks to examine the dissociation between verbal and spatial working memory (i.e., Jenkins et al., 2000). Also, materials and tasks varied across the studies. Objects varied between letters, Arabic characters, and polygons. In some experiments, participants saw objects within a grid, in others they studied objects in a space without grid lines as reference points. Still others constructed spatial tasks where participants had to remember marked locations in the absence of individual objects (Chen et al., 2003; Jenkins et al, 2000). The latter two presentations yielded increased age-related location memory deficits. For tasks, some studies had participants make yes/no recognition judgments while in others they made same-different judgments.

The present research attempts to bring clarity to the question of age-related changes in VSWM. An important feature of the present study is a focus on age-comparisons in the absence of an investigation of the dissociation between the two VSWM components. Thus, we employed no secondary tasks. Consistent with previous research, we used 5 x 5 grids to test item and location VSWM. Thus, participants viewed object-filled grids. Similar to Hale (see Chen et al; Jenkins et al.), we chose to use figures as opposed to letters and characters. Logie and colleagues (e.g., Logie, 1995; Logie & Marchetti, 1991) have suggested that object information is typified by the inability to be actively verbally rehearse. We hypothesized that figures would be more difficult to verbally rehearse as compared to letters or characters. Thus, object memory performance would more likely be a result of visual working memory as compared to verbal working memory. VSWM was tested using a yes-no recognition test. We assessed location memory, object memory, and their conjunction. Depending on condition, participants were instructed to remember the object identities, object locations, or both. Finally, we examined span for locations and objects. Jenkins et al. (2000) demonstrated that older adults showed greater age-related impairment in both object and location memory span (see also Chen et al.). However, in these cases location span was tested by placing the same figure in several locations. In the present experiment we examined how location memory span would be affected when different figures where studied in different locations. With this design, we could test object identity span, location span, and combination span.

Research from several domains comparing location and object memory lead us to hypothesize that, in fact, age will have less of an impact on location memory as compared to object memory. For example, research suggests that extraction and maintenance of spatial locations require less cognitive effort than extraction and maintenance of object information (Hasher & Zacks, 1979; Mandler, Seegmiller, & Day, 1977; Light & Zelinski, 1983; Naveh-Benjamin, 1987). The idea that location information can be extracted less effortfully than identity information has been supported in several contexts (e.g., Ellis, Katz, & Williams, 1987; Mandler, et al., 1977; von Wright, Gebhard, & Karttunen, 1975). Mandler et al. (1977) found that both children and young adults recalled object locations equivalently after attending to either object identities alone (incidental instructions) or both identity and location (intentional instructions). Similarly, von Wright et al. (1975) found no differences between incidental and intentional learning when participants recalled picture locations. More recently, Köhler, Moscovich, and Melo (2001) found that recognition and recall performance for spatial location was equivalent regardless of whether participants made encoding judgments about object identity or spatial relationships. These studies suggest that location information can be learned without intentionality.

Metacognition within the Spatial Domain

Only a handful of studies have examined metacognition in the context of working memory tasks. Those that do exist have primarily focused on strategic control. Further, only one study has examined metacognitive processes with spatial memory tasks. The application of strategic processing that arises from metacognitive monitoring is particularly important for spatial tasks such as navigation and map learning. In the context of VSWM an examination of metacognitive monitoring may further elucidate the dissociation between visual and spatial VSWM components. Specifically, if people extract spatial components less effortfully, it may be difficult for them to accurately predict and then effectively control spatial learning. Thus, a second goal of the present study was to investigate metacognitive processes associated with VSWM.

Even though research has demonstrated that people who report using specific strategies have better working memory ability (Dunlosky & Kane, 2007; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Turley-Ames & Whitfield, 2003), few studies have examined whether participants can metacognitively monitor and implement specific working memory strategies based on those monitoring processes. If individuals can implement useful working memory strategies, this would suggest that they can also monitor working memory processes. Supporting the hypothesis, a recent study comparing older and younger adult working memory metacognitive processes found that younger adults could accurately monitor working memory (Touron, Oransky, Meier, & Hines, 2010). In this span task, participants verified arithmetic solutions while remembering a series of letters. After each trial, participants rated confidence in their memory performance. Importantly, older adults assessed memory performance less accurately, showing greater under-confidence, than younger adults. The relationship between confidence and accuracy was determined by computing gamma correlations (Nelson, 1984). As Touron et al. (2010) note, these results contrast with episodic metamemory findings. Specifically, episodic metamemory research demonstrates age-equivalence when trial-level discrimination was compared in a paired-associates task (Connor, Dunlosky, & Hertzog, 1997; Lovelace, 1990).

Within the spatial memory domain, there has been only one study investigating metacognition. In this investigation, participants studied and made JOLs in association with learning maps. Participants studied each map for 60 seconds in order to determine the way from one town to another and remembered those directions (Schwartz, 2006). Schwartz found that younger adults could successfully predict memory accuracy for directions, demonstrating in an episodic task, that people were aware of spatial knowledge acquisition.

The Present Study

The present research investigates older and younger adults' memorial and metamemorial processes related to the two VSWM components. We examined memory and metamemory for location, object identity, and the combination of both, independently. We predicted age-equivalence for location working memory and age-deficits for object and the combination of both. These predictions are based on VSWM research as well as reading and episodic memory findings demonstrating that location memory may be less effortfully extracted. With regard to metamemory, the one study we could find, suggests that older adults will be poorer monitors than younger adults. However, this study used a complex span task. For object-identity information, a simple working memory task, older adults may demonstrate good monitoring, consistent with the episodic metamemory literature. For combination information, a complex task, consistent with Touron et al., 2010, older adults may have more difficulty monitoring working memory. In three experiments, older and younger adults studied objects presented in 5x5 grids. After studying each grid, participants made Judgments of Learning (JOLs) and completed a yes-no recognition test assessing object-identities, locations, or both in combination. In Experiments 1a and 1b, participants attended to specific grid information (i.e., identities, locations, or both). In Experiment 2, participants did not know what information would be tested; therefore they had to attend to both object identities and locations on every trial.

Experiment 1a

Methods

Participants. The younger adults consisted of Tufts undergraduates who participated either to partially fulfill a course requirement, or for monetary compensation ($10/hr). The older adults consisted of volunteers recruited from a previously established older adult participant pool, and received monetary compensation ($15/hr). Every attempt was made to equally represent both genders and all major ethnic/racial backgrounds. Participants included 25 younger and 25 older adults. We dropped two participants' data, one younger and one older adult, from the analysis due to low recognition accuracy (i.e., more than 2 standard deviations below the mean). Fifteen female and 9 male younger adults (age range 18-26; *M* = 21.3, *SD* = 2.2; education *M* =15.2 years, *SD* =1.6) and 17 female and 7 male older adults (age range 66-84; *M* = 74.0, *SD* =6.3; education *M* =14.5 years, *SD* =2.2) were included. Forty-seven participants were right handed, and three were left handed. Younger and older participants did not statistically differ on handedness, education, or vocabulary scores, *t*'s < 1. Older adults were prescreened for cognitive impairment (Mini Mental State Exam; Folstein, Folstein, & McHugh, 1975) and answered a questionnaire regarding general health and medication use. Specifically, before participating in the study, potential older participants were asked if they had a history of: learning disorders, psychiatric problems, neurological or movement disorders, heart disease, vascular disease, stroke, seizures, drug/alcohol addiction, or diabetes. Potential participants provided a list of medication, indicated whether they had ever been on anti-depressants or anti-anxiety medication, and indicated whether they had ever had electroconvulsive therapy. Older participants recruited for this particular study were those that presented as cognitively healthy as assessed by the MMSE, not suffering from mood disorders, and not presently taking medication that might interfere with cognitive functioning. Thus, older adults were excluded from this study if they were presently taking medication to regulate mood or anxiety, if they had a history of drug/alcohol abuse, if they had any neurological disorders, vascular disease, or heart disease, a history of strokes, seizures, or diabetes.

Design. We used a 2 (Age: *Older adults, Younger adults*) X 3 (Question Type: *Identity, Location, Combination*) X 4 (Array Size: *2,3,4,5*) mixed factorial design, with question type and array size serving as within-participants variables, and age serving as a between-participant variable.

Materials

The to-be-studied spatial information consisted of 5x5 grids containing between two to five objects. Objects were drawn from a pool of twenty 2-D simple line drawings. A total of 144 grids were used: 36 2-object, 36 3-object, 36 4-object, and 36 5-object. We constructed grids so that the objects and corresponding locations were randomly chosen, consistent with certain constraints. For instance, we used an object or location a relatively equal number of times. Out of 144 grids (504 possible object identities and locations), each object was used between 24-28 times and each location was used between 18-21 times. A specific object could not be presented in the same location more than three times. In addition, any two objects or any two locations could not be used together within the same grid more than five times. A questionnaire inquired about age, gender, amount of formal education, handedness, and immediate family member handedness. The questionnaire also asked whether participants prefer verbal descriptions or maps when getting travel directions.

Procedure

Instructions informed participants that they "will be presented with a series of displays containing various shapes in various locations within a grid." Participants attended to either identities, locations, or both in combination depending on an experimental block. Trials were blocked by condition (i.e. identity, location, or combination), with trials randomized within each block. Before each block, participants were informed as to what information was to be tested. Block order was counterbalanced. Preliminary analyses revealed no significant order effects.

Every experimental trial used a similar 3-part procedure wherein participants viewed a grid, made a JOL, and then completed a yes-no recognition test. Presentation of stimuli was done via SuperLab 4 on Mac OS X computers. Grid presentation involved a central fixation cross (500ms) followed by a grid. Younger adults studied grids for 500ms and older adults studied for

3000ms. We varied study time in order to ensure similar levels of encoding between older and younger adults. Pilot testing revealed above chance performance for older and younger adults with the chosen presentation times when five object arrays were studied. After study, a mask and another fixation cross appeared, both for 500ms. For JOLs, participants rated "How likely are you to remember _______ on this previous grid on an immediate test of memory?"

Depending on the trial, the _____ was filled with either "the shapes", "the locations of shapes", or "the shapes and the locations of the shapes". We paired the question with a Likert scale ranging from 0 (*not likely at all*) to 10 (*extremely likely*). To assess grid memory we used a yes-no forced choice recognition test focusing on either identities, locations, or both in combination, depending on the experimental block (with 48 trials in each block). In all cases, 1/3 of the questions contained previously studied information and 2/3 contained incorrect lures. This type of construction was adopted to engender a conservative responding strategy, as the distribution of hits would be smaller than the distribution of false alarms. In object identity trials, participants saw studied (correct) or unstudied (incorrect lures) objects and answered "Was this shape presented in the previous grid?" Objects appeared independent of the grid. In location trials, participants answered "Was an object presented in this location in the previous grid?" The question appeared with an objectless grid with either a studied location (correct) or an unstudied location (incorrect lure) highlighted in red. In combination object/ location trials, participants answered "Was this object presented in this location in the previous grid?" The question was paired with a grid containing either a studied object in its studied location (correct) or the following four types of incorrect lures: 1) a studied object in an new unstudied location ("new-location/old-identity"), an incorrectly paired object and location in which both had been studied but in a different combination ("previously studied-location/previously studied-identity"), a new unstudied object in an new unstudied location ("new-location/new-identity"), or a new unstudied object in a studied object location ("old-location/new-identity"). Figure 2 illustrates a sample grid presentation. After each trial, there was a 500 ms interval followed by the next trial.

Results

Accuracy. Recognition test accuracy was evaluated by a 2 (Age: Older Adults, Younger Adults) X 3 (Question Type: Identity, Location, Combination) X 4 (Array Size: 2, 3, 4, 5) mixed-factor ANOVA. The analysis yielded main effects of Array Size, $F(3,138) = 69.01$, $p < .001$; and Question Type, $F(2,92) = 35.39$, $p < .001$. Figures 3 illustrate that as the array size increased, participants became less accurate (Means: 2 = .90, 3 = .81, 4 = .77, & 5 = .76). In addition, participants were less accurate in combination trials ($M = .76$) than on identity trials ($M = .81$), $t(47) = 3.95$, $d = .62$, and more accurate in location trials ($M = .86$) as compared to identity trials, $t(47) = 3.90$, $d = .71$.

We also found an interaction between Age and Array Size, $F(3, 138) = 2.88$, $p < .05$. Older adults were less accurate than younger adults with five-object arrays, $t(46) = 2.47$, $p < .05$, $d = .76$. Age did not affect performance for any other array size. An interaction between Question Type and Age was also found, $F(2, 92) = 3.33$, $p < .05$. Older adults' combination trial accuracy ($M = .74$) was worse than younger adults ($M = .79$); however, for identity and location trials, older and younger adults produced statistically equivalent results, t's < 1. Finally, we found an interaction between Question Type and Array Size, $F(6, 276) = 8.94$, $< .001$; as the array size increased, participants were less accurate on both identity (*Means:* 2 = .94, 3 = .80, 4 = .78, & 5 = .73) and combination trials (*Means:* 2 = .87, 3 = .77, 4 = .69, & 5 = .72). For location trials, accuracy remained relatively stable (*Means:* 2 = .89, 3 = .86, 4 = .84, & 5 = .84) as array size increased.

Judgments of Learning - Resolution. We computed Goodman-Kruskal gamma (γ) correlations between JOLs and recognition to examine JOL predictive accuracy, or resolution. These correlations reflect the degree to which individual differences in predictions accurately reflect individual differences in recognition. By examining changes across trials, participants' knowledge of the relative effectiveness of specific cues can be assessed. For the gamma (γ) correlation index, large positive values correspond to a strong association between memory performance and judgments, values close to 0 correspond to no association, and negative values correspond to an inverse relationship. As gamma correlations cannot be computed when either recognition or JOLs lack variability, the comparison on prediction accuracy was done by collapsing across the array size variable. This analysis increased gamma stability as it reduced the chances of an undetermined gamma. Thus, three gamma correlations were computed for each participant, one for the identity block, one for the location block, and one for the combination block. Even collapsing across array, gamma correlations could not be computed for three older adults and one younger adult. A 2 (Age: Older Adults, Younger Adults) X 3 (Question Type: Identity, Location, Combination) mixed-factor ANOVA on gamma correlations found a main effect of Question Type, $F(2, 88) = 3.33$, $p < .05$. As Table 1 illustrates, participants predicted their future recognition performance better on identity trials (M = .39) as compared to both combination (M = .22) trials, $t(47) = 2.66$, d = .52, and location trials, $t(45) = 2.40$, d = .53. There was no statistical difference between prediction accuracy associated with combination trials and location trials. It should be noted, however, that prediction accuracy for each trial type and each age group was significantly better than chance. No other effects were significant.

Judgments of Learning - Calibration. Calibration, or the difference between confidence and correctness, was captured by bias scores. Bias assessed the degree to which an individual is under- or over-confident, as measured by confidence judgments (Schraw, 2009). To parallel the resolution analysis, we computed three bias scores for each participant, one for object-identity, one for location, and on the combination trials. A 2 (Age: Younger, Older) x 2 (Question Type: Identity, Location, Combination) mixed ANOVA found a main effect of Question Type, $F(2, 92) = 4.29$, $p < .05$. As Table 2 illustrates, participants were under-confident for all question types, but more so for location (M = -0.25) and combination (M = -0.24) trials as compared to identity trials (M = -0.20). In addition, we found an interaction between Question Type and Age, $F(2, 92) = 5.45$, $p < .01$. Older adults were more under-confident on location trials ($M = -0.30$) than were younger adults ($M = -0.20$). Older and younger adults did not differ in bias associated with identity or combination trials.

Discussion

Both older and younger adults demonstrated superior location memory as compared to object and combination object/location memory. Further, location memory was less affected by array size as compared to object and combination memory. Taken together these findings suggest that location information may be more easily processed than object memory within the current paradigm. In addition, we found that while older and younger adults did not differ on object or location memory, older adults had more difficulty remembering combined location and object information. Even under different encoding procedures, older adults demonstrated a deficit in memory performance on combination trials. The absence of an age effect for object memory was not surprising, as presentation times where selected to facilitate similar levels of encoding between older and younger adults. Finally, we found that both older and younger adults could monitor VSWM, as prediction accuracy (gamma) was significantly above chance for all question types. Importantly, both groups were more accurate when monitoring identity learning as opposed to location learning.

Although manipulating presentation rate is a standard practice for equalizing difficulty between older and younger adults, the presentation rate differences may have resulted in the recruitment of fundamentally different encoding processes. Therefore, Experiment 1b tested age-equivalence in monitoring accuracy under conditions where presentation time did not differ between age group. Study time for each grid was increased for younger adults and decreased for older adults. We predicted that increasing study time would improve younger adults' VMWM and metamemory performance. Further, we predicted that the decrease in study time for older adults would negatively impact identity and combination memory, but have no impact on location memory. Finally, we did not expect the change in study time to impact older adults' metamemory prediction accuracy.

Experiment 1b

Methods

Participants. Participants included 25 young and 25 older adults. Two participants' data were dropped from the analysis, one younger and one older adult, due to low recognition accuracy (i.e., more than 2 standard deviations below the mean). Sixteen female and 8 male younger adults (age range 18-23; *M* = 19.3, *SD* = 1.6; education *M* = 13.9 years, SD = 1.8) and 18 female and 6 male older adults (age range 59-96; *M* = 74.3, *SD* =8.7; education *M* = 15.0 years, SD = 2.5) participated. Forty-two participants were right handed and eight participants were left handed. Older and younger adults did not statistically differ on handedness, years of education, or vocabulary scores, *t*'s < 1. Older adult were screened as in Experiment 1a.

Procedure. The materials and procedure matched those used in Experiment 1a, except that both older and younger adults saw each grid for 1500 ms.

Results

Accuracy. We analyzed recognition accuracy as in Experiment 1a. We found main effects for Question Type, Array Size, and Age [$F(2, 92) = 52.81$, $p < .01$; $F(3, 138) = 109.60$, $p < .01$; $F(1, 46) = 36.87$, $p < 01$]. As Figures 4 illustrates, participants responded more accurately on location trials ($M = .85$) as compared to object identity trials ($M = .81$), $t(47) = 3.56$, $d = .42$, and as compared to combination trials, $t(47) = 10.04$, $d = 1.19$. They also performed more accurately on object identity as compared to combination trials, $t(47) = 6.38$, $d = .72$. Participants also were less accurate as the array size increased (Means: 2 = .89, 3 = .81, 4 = .77, & 5 = .72), with significant decreases in accuracy from two to three objects, $t(47) = 8.29$, p < .01, $d = .80$; from three to four objects, $t(47) = 4.01$, p< .01, $d = .82$; and from four to five objects, $t(47) = 6.15$, $d = .59$. Finally, unlike Experiment 1a, we found that older adults made more recognition errors ($M = .74$) than younger adults ($M = .86$).

We also found an interaction between Question Type and Array Size, $F(6, 276) = 11.75$, p < .001. Participants were less accurate on both identity (*Means:* 2 = .93, 3 = .79, 4 = .81, & 5 = .71) and combination trials (*Means:* 2 = .84, 3 = .79, 4 = .67, & 5 = .62) as the array size increased. Note, the difference between array size ‘3’ and ‘4’ was not significant for identity trials. For location trials, with the exception of a significant drop in performance between array size ‘2’ and ‘3’, t(47) = 3.11, d = .16, participants’ accuracy remained stable (*Means:* 2 = .90, 3 = .84, 4 = .83, & 5 = .84) with increasing array size. We also found an interaction among Question Type, Array Size, and Age, $F(6, 276) = 5.04$, $MSe = .01$, $p < .001$. An age deficit was found across all question types and array sizes, except for array size ‘5’ on combination trials. We found no other main effects or interactions, *Fs* < .1.

Judgments of Learning - Resolution. The analysis of gamma correlations yielded a main effect of Question Type, $F(2, 90) = 3.37$, $MSe = .11$, $p < .05$. Participants better predicted future identity recognition performance ($M = .41$), as compared to location ($M = .26$) and combination ($M = .25$) performance. We also found a main effect of Age, $F(1, 45) = 8.69$, $MSe = .04$, $p < .01$; younger adults ($M = .39$) more accurately predicted recognition than did older adults ($M = .23$). An interaction between Question Type and Age was also found, $F(2, 90) = 3.79$, $MSe = .11$, $p < .05$. As Table 1 illustrates, older adults more accurately predicted identity memory ($M = .41$) followed by combination memory ($M = .18$), and were least accurate for location memory predictions ($M = .08$). The location trial gamma was not significantly different than 0, $t(23) = 1.06$, $p = .31$. Younger adults’ prediction accuracy, on the other hand, was statistically equivalent for all question types (*Means:* identity = .41, location = .45, combination = .33).

Calibration. When calibration was examined using bias scores we found a main effect of question type, $F(2, 92) = 5.94$, $p < .05$. While participants were under-confident for all question types, they were more so for location ($M = -0.24$) and combination ($M = -0.22$) trials as compared to identity trials ($M = -0.18$). We found no other significant effects, $F < 1$.

Discussion

Experiment 1b equated study time for both age groups. Compared to Experiment 1a, this meant more study time for younger adults and less study time for older adults. With this change, we found an overall age difference not evident in Experiment 1a. Specifically, older adults’ identity, location, and combination recognition was worse than that of younger adults. In addition, age differences in prediction accuracy emerged. Whereas equated study time resulted in age differences in this experiment, as in Experiment 1a, both older and younger adults made the fewest errors when recognizing location in isolation. Moreover, like Experiment 1a, location memory was less affected by increasing array size.

Both younger and older adult metacognitive prediction accuracy was impacted by the change in study time. That is, with the increase in study time, younger adults better predicted future memory performance. Further, younger adults predicted memory similarly across memory test types. Relative to Experiment 1a, this means that younger adults' prediction accuracy on location trials improved with more study time. On the other hand, with the decrease in study time, older adults could no longer predict memory performance associated with location trials; however, older adults could still somewhat accurately predict memory on identity and combination trials.

Experiment 2

Experiment 1 (a and b) suggests differential processing of location, relative to identity and combined location/identity, information in VSWM in both older and younger adults. Notably, location memory appears to be more easily processed, remaining relatively stable as the number of to-be-remembered items increased. Further, while location memory appeared to be more easily processed, under certain conditions participants could monitor location memory performance. Specifically, both age groups could better monitor location information when given more time to study; however, older adults could not monitor location memory with less study time. Thus, older adults demonstrated good and stable location memory, but could not predict locations that they would and would not remember.

While this dissociation between memorial and metamemorial processing of location information is interesting, the results could, in part, reflect strategic processing. With the blocked design in these studies, participants knew which information would be tested and could have focused on this information during study. In addition, the increased underestimation bias older adults demonstrated for location memory, suggests that older adults may not be aware that location information may be less effortfully processed. As such, when told location memory would be tested, older adults may have engaged unnecessary cognitive effort toward processing location information. Similarly, when presented with combination trials, older adults may have directed more attention than necessary towards location information, and not enough toward identity information or binding identity to the location.

In Experiment 2, we examined whether eliminating the ability to strategically attend to specific grid information (i.e., identity, location, or both) would influence memory and metamemorial accuracy in this VSWM task. Learning goals and strategies influence performance by changing how people process information. They may activate relevant schemas (Pichert & Anderson, 1977) and/or direct attention (e.g., Britton, Meyer, Simpson, Holdredge, & Curry, 1979; Brunyé & Taylor, 2009; LaBerge, 1995), and those goals may act as retrieval cues (Anderson & Pichert, 1978). Experiment 2 removed strategic processing by randomly testing participants on identity, location, or combination information. Participants studied 5x5 grids, but did not know what information from each grid would be tested. To be successful, participants had to study all grid information. If location is less effortfully processed, then location memory should still show an advantage. In contrast, object-identity information, which may benefit from strategic attentional focus, may suffer.

Methods

Participants. Participants included 25 younger and 25 older adults. We dropped two participants' data, one younger and one older adult, from the analysis due to low recognition accuracy (i.e., more than 2 standard deviations below the mean). Twelve female and 12 male younger adults (age range 18-22; *M* = 19.9, *SD* = 1.2; education *M* = 14.0 years, SD = 1.7) and 14 female and 10 male older adults (age range 63-82; *M* = 74.1, *SD* = 5.6; education *M* = 16.1 years; SD = 3.2) were included. Thirty-eight participants were right handed, and 12 participants were left handed. Younger and older adults did not differ on education, vocabulary scores, or handedness, $t < 1$. We used the same screening procedures for older adults.

Design. All experimental trials were randomized within 3 blocks. Blocks contained equal numbers of object identity, spatial location, and combination trials. The presentation order of the randomized blocks was counterbalanced.

Procedure. Participants were instructed to attend to both identity and location information for all trials. Following 1500 ms grid presentation, participants made the following JOL: How likely are you to remember the *information* on the previous grid? We used the same scale as in previous experiments. The JOL question was modified so as to not cue the information that would be tested. Participants completed an object identity, spatial location, or combination judgment.

Results

Accuracy. Recognition accuracy was analyzed as in Experiment 1. The analysis yielded an effect of array size, $F(3, 138) = 72.63$, $p < .001$; as the array size increased, participants were less accurate (*Means:* 2 = .82, 3 = .74, 4 = .70, & 5 = .64). In addition, we found an effect of Question Type, $F(2, 92) = 3.60$, $p < .001$. As Figures 5 illustrates, participants made the most accurate on identity (*M* = .74) and location trials (*M* = .74), and least accurate on combination trials (*M* = .70). We also found a main effect of Age, $F(1,46) = 55.33$, $p < .001$; older adults were less accurate (*M* = .66) than younger adults (*M* = .78). The analysis also yielded an interaction between Question Type and Array Size, $F(6, 276) = 6.31$, $p < .001$. Like previous experiments, as array size increased participants accuracy decreased on both identity (*Means:* 2 = .88, 3 = .73, 4 = .71, & 5 = .62) and combination trials (*Means:* 2 = .77, 3 = .76, 4 = .65, & 5 = .60). Conversely, after an initial dip in performance after 2 items, participants' location trial accuracy remained constant (*Means:* 2 = .83, 3 = .71, 4 = .74, & 5 = .69) as array size increased (ts < .1). We found no other main effects or interactions, *Fs* < .1.

Resolution and Calibration. In Experiment 2, participants were not aware of which test type would occur on a given trial. Under these conditions, we expected that participants would study all aspects of the grid. Further, participants answered a metacognitive question that asked for a prediction regarding grid memory, with no specification of location or identity information. As such, we computed gamma correlations for only combination trials. A t-test comparing older and younger adults yielded a significant effect, $t(45) = 3.32$, $d = .79$. As in the previous experiments, younger adults (*M* = .31) more accurately predicted future performance than did older adults (*M* = .19). A t-test comparing older and younger adults' average bias scores on combination trials did not yield a significant difference, $t < 1$.

Discussion

Experiment 2 was designed to rule out the possibility that participants' knowledge of to-be-tested information contributed to their recognition and metacognitive accuracy, especially on location trials. Similar to Experiment 1, Experiment 2 combination trials resulted in the lowest accuracy. For location trials, strategic processing partially, but not fully, contributed to the previously seen "location advantage." Specifically, in the present experiment, we found that location memory was not overall superior to identity memory for either age group. However, results from Experiment 2 further support the conclusion that location information is less effortfully processed as it was less sensitive to array size than identity or combination information. After two items, performance stayed relatively stable. Identity and combination memory on the other hand decreased as array size increased. Finally, as in Experiment 1b, younger adults better predicted future memory performance than did older adults.

General Discussion

The present study sought to determine age-related performance in VSWM. VSWM can be decomposed into memory for object-identity, spatial location, and the combination of these two. Specifically, the studies sought to determine whether age similarly impacted both memory and metamemorial predictions about object-identity, spatial locations, and their combination. To date, only one study has examined metacognitive processes within the working memory context (Touron et al., 2010), and only one study has examined metacognitive processes with a spatial task (Schwartz, 2006). Based on these studies, as well as the episodic metacognition research, we predicted that older and younger adults would demonstrate comparable levels of metacognitive accuracy, as measured by gamma correlations, when predicting performance on identity and location trials; however, when the working memory task was more complex (i.e., combination trials) we predicted that age differences would emerge.

Across all experiments, older adults had more difficulty than younger adults with the more complex WM task, i.e., when memory for identity and location were tested in combination. This difference held even when older adults had more time to study grids (Experiment 1a). Interestingly, both older and younger adults predicted their own combination memory with above chance accuracy; however, younger adults were more accurate than older adults. This is consistent with previous research demonstrating age-deficits in metacognitive accuracy for a complex working memory task (i.e., Touron et al., 2010), but inconsistent with the pervasive finding in the episodic memory literature for age-equivalence in metacognitive monitoring. We hypothesized that for our complex work memory task multiple cues could be useful in assessing future memory performance. Older adults may have more difficulty appropriately weighing the relevance of each accessible cue. For combination trials, participants can access information about processing ease as well as information about task and item difficulty. When multiple pieces of information are involved, older adults may rely on less diagnostic cues. It is also possible that the build-up of proactive interference impacted older adults' monitoring performance (e.g., Eakin & Hertzog, 2006; Lustig, May, & Hasher, 2001). The present experiments do not differentiate among these possible explanations. However, the present study is the first to demonstrate both age-deficits and age-equivalence in metacognitive prediction accuracy within a working memory paradigm.

Memory

Study time impacted age-related effects on the constituent parts of VSWM, specifically object-identity and spatial location memory. When study time was equated (Experiment 1b), age differences emerged across all VSWM components. However, when older adults had additional study time, age differences in object identity, and spatial location memory, tested in isolation, disappeared. Further, strategic processing appeared to influence object-identity and spatial location memory. When participants knew what information would be tested, both younger and older adults remembered location information better. This is consistent with Salthouse (1995) who showed that greater age differences with identity compared location memory. Further, as the number of objects in the grid increased location memory performance remained stable in both older and younger adults. When the to-be-tested information could not be predicted (Experiment 2), the overall difference between identity and location memory largely disappeared; however location memory still remained relatively stable across array size.

Two findings suggest that location information may be more easily processed than identity information (Hasher & Zacks, 1979; Lovelace, & Southall, 1983; Rothkopf, 1971). First, array size only minimally impacted location memory. Second, instructions to study location information led to better location (compared to identity) memory for both older and younger adults. Although some have argued that location information may be automatically extracted, our findings are not consistent with this view. With study time equated, age differences in location memory emerged. Further, when not strategically processed, the location memory advantage disappeared. Put another way, location memory did benefit from intentionality in the present study. According to Hasher and Zacks' (1979) criteria for automaticity, neither age nor strategic processing should affect location memory. Thus, our findings suggest that while location memory may require less effort than identity information, it is not processed automatically. This is consistent with Naveh-Benjamin's (1987) suggestion that spatial location might fall within a continuum between "automatic" and "effortful" processing. Alternatively, spatial location learning may involve multiple processes, only some of which are automatic (Naveh-Benjamin, 1987). Manipulations such as encoding strategy and encoding time may only affect the more effortful location-based processes.

Finally, across all experiments older adults performed less well than younger adults on combination trials. The finding that older adults are less successful at binding focal elements to contextual elements in long-term memory has been well established (Bayen, Phelps, & Spaniol, 2000; Chalfonte & Johnson, 1996; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000;

Naveh-Benjamin, 2000; Naveh-Benjamin & Craik, 1995). Less well understood is whether this associative recognition, or binding, deficit extends to VSWM. In the present study, in order to succeed on combination trials, participants were required to remember both the identity of an object and the location of that object. That is, binding of identity and location information was necessary to perform the task. We found that older adults performed less well on combination trials as compared to younger adults, and consist with previous research in the working memory domain (Cowan, Naveh-Benjamin, Kilb, & Saults, 2006; Mitchell, et al., 2000). Further, even when given six times more study opportunity per trial than younger adults, older adults continued to perform less well on combination trials. While the extended study did not eliminate age-related differences in combination memory, it did eliminate differences in identity memory. Age-related differences in identity memory were present when study time was equated. Taken together, these results suggest that, as in the episodic long-term memory literature, an age-related binding deficit may be present in VSWM. However, this binding deficit may not extend to all features in a visual-spatial array (see Brockmole, Parra, Della Sala, & Logie, 2008; Brown & Brockmole, 2010).

Metamemory

Identity and location metamemory also appear sensitive to study time. Older adults could not predict location memory performance when given less time to study. Further, the advantage of identity predictions over location predictions persisted, regardless of study time, in older adults. Similarly, younger adults predicted identity memory better than location memory with reduced study time; however, this advantage disappeared with more study time. Finally, when study time was equated, age differences in prediction accuracy across identity and combination trials emerged.

These findings suggest that older adults may need additional time to evaluate potentially useful cues when making metacognitive predictions or they may inappropriately weigh certain cues that are present across all trial types. Specifically, when studying for identity, location, or both, the objects' identity stands out as an obvious cue. For location predictions, identity is likely an irrelevant cue; however older adults may inappropriately rely on it when making location predictions. Still another possibility is that older adults may monitor location memory less effectively due to a general inability to use mnemonic indictors for metacognitive predictions. According to Koriat (1997) phenomenal experiences that accompany information processing, or mnemonic cues, serve as input for metacognitive judgments, including JOLs. Several mnemonic cues have been considered, including the accessibility of pertinent information (Dunlosky & Nelson, 1992; Koriat, 1993; Morris, 1990; Thomas, Bulevich, & Dubois, 2011), the ease with which information comes to mind (Kelley & Lindsay, 1993; Koriat, 1993; Mazzoni & Nelson, 1995), and the ease of processing a presented item (Benjamin & Bjork, 1996; Begg et al., 1989). In the present study, location information appears to be processed less effortfully than identity information. Young adults may have considered processing ease when making JOLs for location information, whereas older adults could not.

In contrast with location information, identity information may be intrinsic to the to-be-remembered grids. With reduced study time, both older and younger adults provided the most accurate identity memory predictions. According to the cue-utilization framework (Koriat, 1997), intrinsic properties, or cues, disclose a-priori ease or difficulty of learning. In the case of single words within an episodic memory task, imagery value can indicate memorability (Begg et al., 1989; Groninger, 1979). The type and number of objects presented within a grid likely carry memorability cues that both older and younger adults use when predicting future performance.

Several episodic metamemory studies show age-equivalence in prediction accuracy when intrinsic properties of to-be-remember items were accessible features (Hertzog, Kidder, Dunlosky, Powell-Moman, 2002; Matvey et al., 2002). Novel in the present study is the demonstration that both older and younger adults use this cue within a working memory context.

Several studies have demonstrated age deficits in episodic metacognitive tasks when mnemonic cues were relevant to the prediction task. For example Thomas et al. (2011) demonstrated that younger adults successfully predicted future recognition for presently unrecallable targets using retrieved partial information. Older adults could not use this mnemonic cue unless explicitly directed to do so. Based on previous episodic memory research, it is not surprising that older adults were less able to make accurate metacognitive predictions in conditions where mnemonic cues serve as the most useful cue for the judgment.

Conclusion

The present study makes two important contributions to the working memory literature. First, we found that while not spared by the deleterious effects of aging, older adults performed better in VSWM tasks that examined object identity and object location independently as compared to the combination of location and object. Further, object location memory was minimally affected by array size in both age groups. Previous research examining identity and location memory in older adults have yielded conflicting results. In the present study, where participants did not perform secondary tasks, we did find age-related deficits, particularly with combination trials. Further, when older adults had more time to study, age differences in location and identity memory disappeared, though differences in combination memory remained. These results suggest that age-related working memory deficits may result from age-related processing

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speed difference (cf. Salthouse, 1996) as well as task complexity. Age differences may be less apparent in simple working memory tasks.

Second, this is the first study to demonstrate age-deficits and age-equivalence in working *meta*-memory. When asked to predict future memory performance, prediction accuracy was similar between older and younger adults. However, age-equivalence only resulted when younger adults had less study time and older adults had more time per grid. We use the cue-utilization framework (cf. Koriat, 1997) as a model to understand the present working *meta*-memory findings; however, that framework was developed in the context of episodic and semantic memory tasks, and does not account for the contribution of proactive interference to prediction accuracy.

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Table 1. *Experiments 1a and 1b Gamma correlation Means and Standard Deviations for Older and Younger Adults by Question Type.*

		Question Type					
		Identity		Location		Combo	
Exp	Age	M	SD	M	SD	M	SD
Exp 1a	Older Adults	.38	.31	.20	.46	.19	.28
	Younger Adults	.37	.34	.15	.48	.24	.32
Exp 1b	Older Adults	.42	.21	.08	.39	.18	.25
	Younger Adults	.41	.38	.45	.38	.33	.34

Table 2. *Experiments 1a and 1b Average Bias Scores and Standard Deviations for Older and Younger Adults by Question Type.*

			Question Type		
			Identity	Location	Combo
Exp	Age	Bias	M SD	M SD	M SD
Exp 1a	Older Adults		-.21 (.20)	-.30 (.23)	-.24 (.18)
	Younger Adults		-.19 (.14)	-.20 (.14)	-.24 (.12)
Exp 1b	Older Adults		-.18 (.20)	-.26 (.21)	-.19 (.25)
	Younger Adults		-.17 (.10)	-.22 (.10)	-.23 (.12)

Figure Captions

Figure 1. The twenty possible simple 2D objects that could be placed within the study grids.

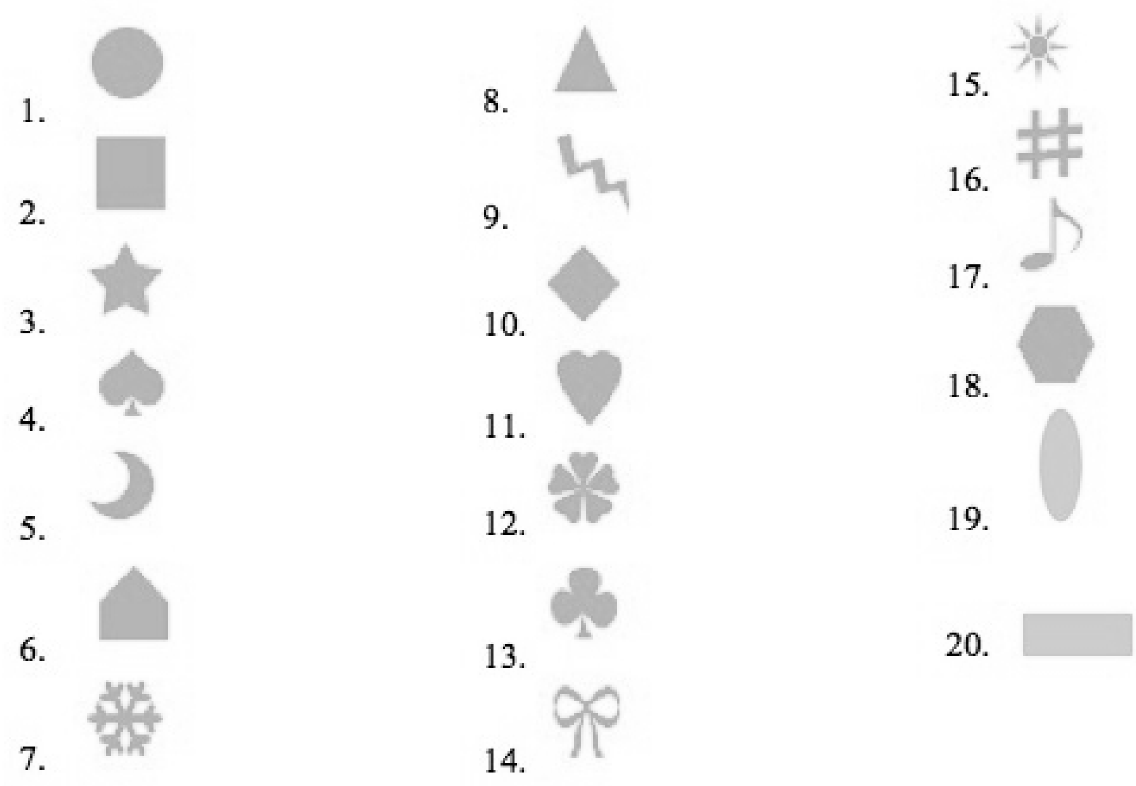
Figure 2. *Top left* - Sample study grid (4 items). *Top Right* - Sample identity recognition question. *Bottom Left* - Sample location recognition question. *Bottom Right* - Sample identity-location combination recognition question.

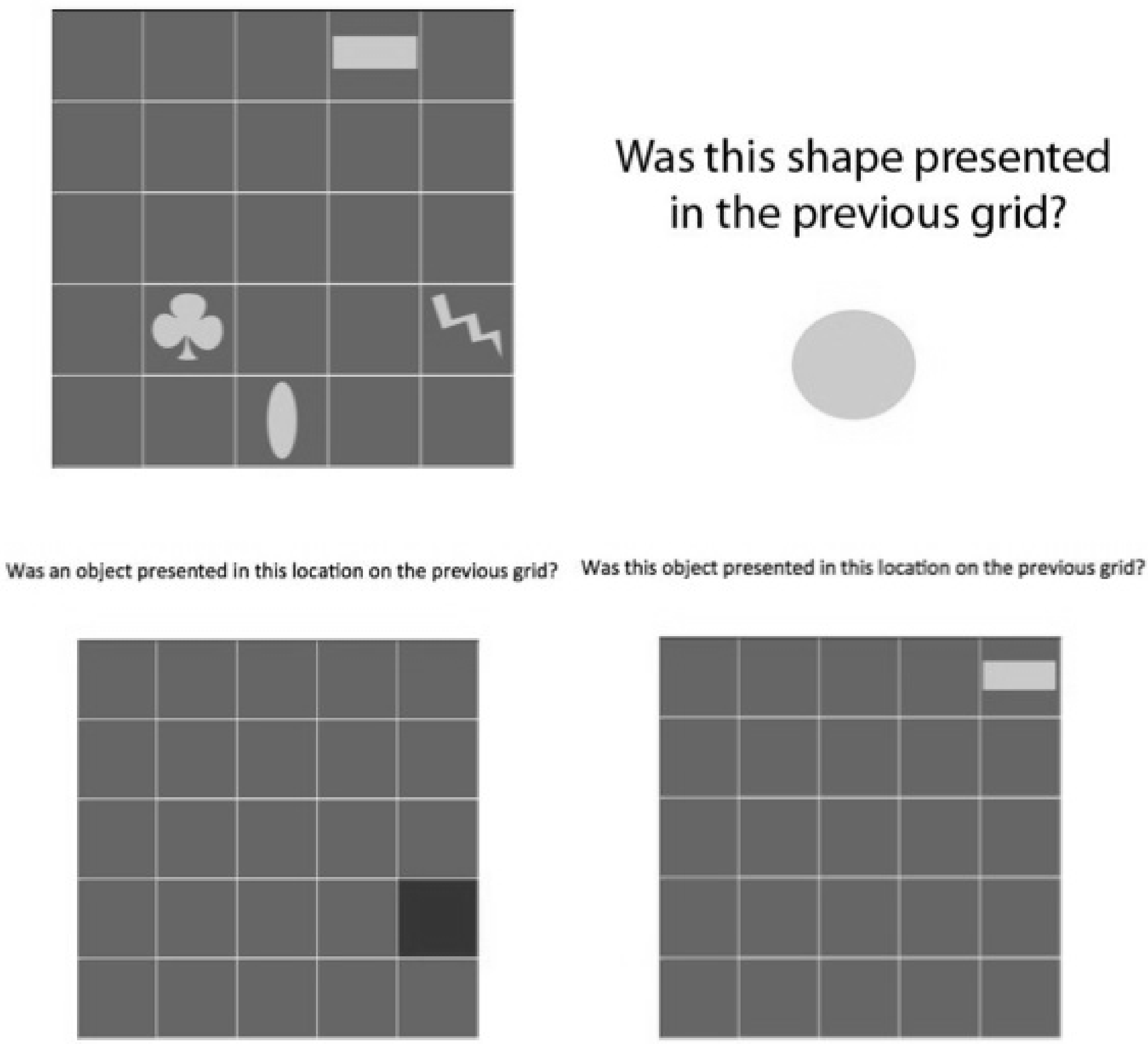
Figure 3. Experiment 1a recognition accuracy, mean proportion correct for question type (identity, location, combination) by array size (2, 3, 4, 5).

Figure 4. Experiment 1b recognition accuracy, mean proportion correct for question type (identity, location, combination) by array size (2, 3, 4, 5).

Figure 5. Experiment 2 recognition accuracy, mean proportion correct for question type (identity, location, combination) by array size (2, 3, 4, 5).

1

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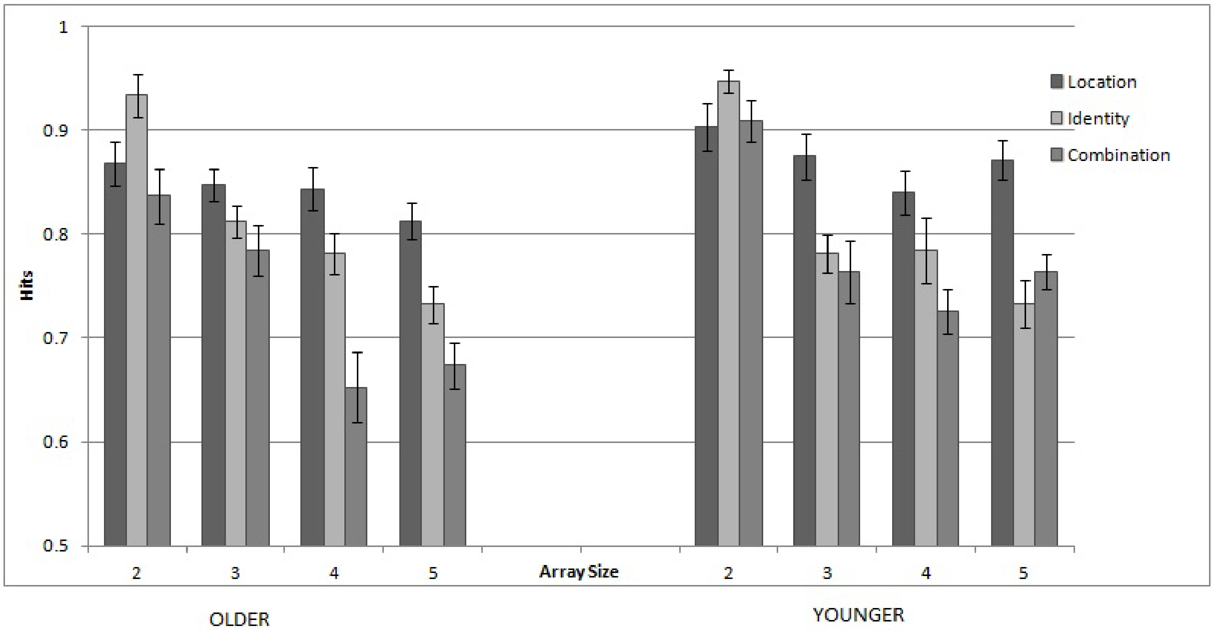
Was this object presented in this location on the previous grid?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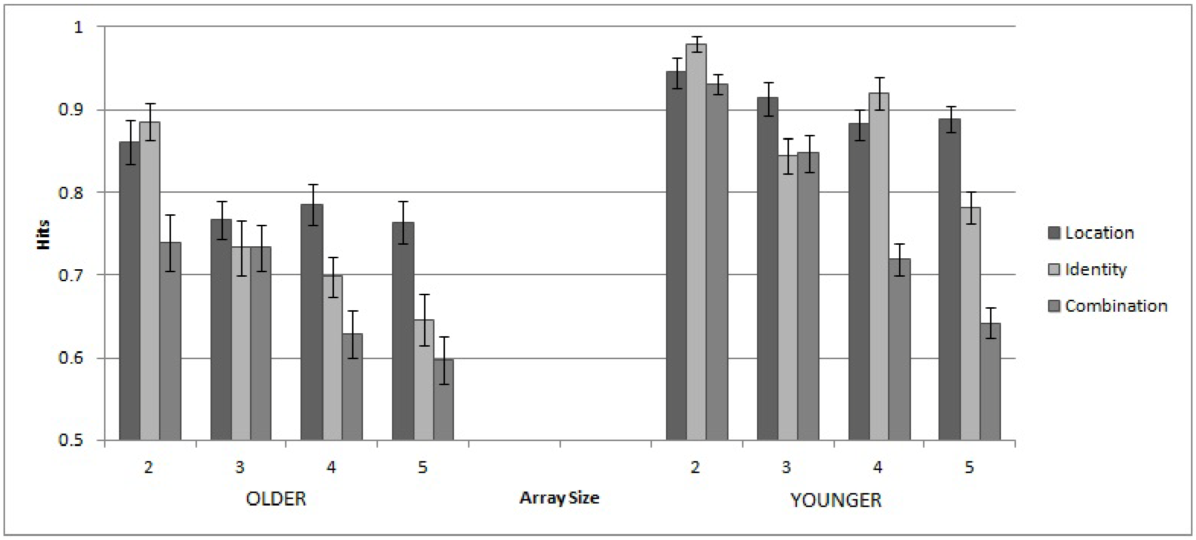
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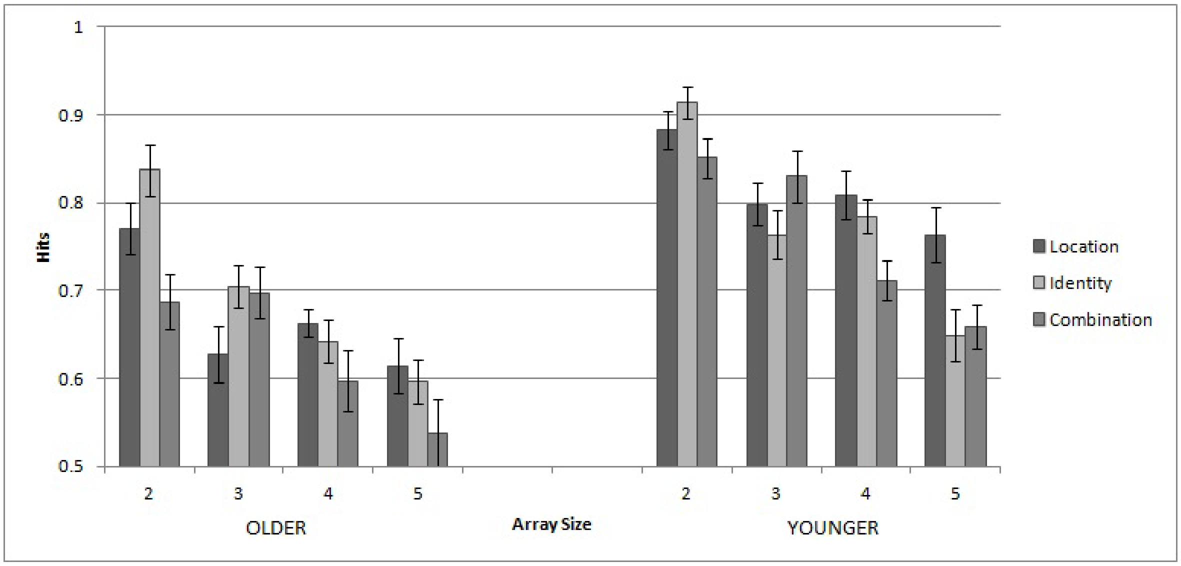
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