The "Where" and the "What": Aging and Visuo-spatial Working Memory

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Ruizhi Dai

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Adviser:

Dr. Holly A. Taylor

Dr. Ayanna K. Thomas

Abstract

Visuo-spatial working memory (VSWM) processes two attributes: object identity and spatial location. Previous research suggests that object processing and location processing may have asymmetric demands for cognitive resources. The present research aims at understanding the relationship between these VSWM attributes, how they are separately processed and bound, and whether the factors that independently influence visual or spatial processing also affect their interaction. Toward this end, we systematically manipulated spatial organization, semantic association, and strategic processing to examine how these factors interact and influence VSWM processing in different age groups. We found that spatial organization, semantic association, and strategic processing differentially affected younger and older adults' VSWM processing. Specifically, younger adults tend to rely on spatial processing whereas older adults tend to rely on semantic processing. We also found that comparing with younger adults, older adults may use strategic processing less effectively and may need more explicit environmental support in VSWM.

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Introduction

Knowing where an object is located in the world requires memory for the object's identity, its location, and crucially the accurate binding of the two. However, object and location information do not always successfully bind, a situation exacerbated by age. Failures in binding object with location information can result in a variety of problems. As one example, the consequences of failing to locate acutely needed medication could be very serious. To reduce such failures, we need to consider factors that may influence "what" and "where" binding. In four experiments, we explored factors influencing object-location binding using a visuo-spatial working memory (VSWM) paradigm, with special interest in age-related differences.

Visuo-spatial Working Memory

VSWM, according to Baddeley and Hitch (1974), is the sub-system of working memory that deals with visual and spatial information. Accurate VSWM requires memory for the object identity, its location, and the combination of both attributes. Through binding, object identity and spatial location information interact (Johnston, & Pashler, 1990). Numerous studies examining the neurological underpinnings of visual processing indicate two neural processing streams: the "ventral" stream that deals with object identity ("what") processing,

and the "dorsal" stream that engages in location ("where") processing (Mishkin, & Ungerleider, 1982; Goodale, & Humphrey, 1998). Previous research suggests that object processing and location processing may have asymmetric cognitive resource demands (Hasher, & Zacks, 1979; Huang, Treisman, & Pashler, 2007; Johnston, & Pashler, 1990; Thomas, Bonura, Taylor, & Brunyé, 2012; Taylor, Thomas, Artuso, & Eastman, 2014). Location processing seems to require only limited effort (Pezdek, 1983; Thomas, Bonura, Taylor, & Brunyé, 2012), whereas object processing requires greater effort (Huang, Treisman, & Pashler, 2007; Johnston, & Pashler, 1990; Taylor, Thomas, Artuso, & Eastman, 2014).

This cognitive resource asymmetry has led to a heated debate on whether location encoding is automatic. Hasher and Zacks (1979) proposed that to be considered as automatic, cognitive operations must occur without intention, do not benefit from instructions or practice, are not disrupted by concurrent demanding processes or influenced by stress, and develop early and remain relatively stable in life (Hasher, & Zacks, 1979). Research on whether location processing meets these criteria yielded different findings. Some researchers argued that location information is automatically encoded, requiring little cognitive resources (Köhler, Moscovich, & Melo, 2001), is not influenced by intentional instructions (Mandler, Seegmiller, & Day, 1977; von Wright, Gebhard, & Karttunen, 1975), and does not vary across the lifespan (Mandler, Seegmiller,

& Day, 1977; Ellis, Katz, & Williams, 1987). For example, Mandler, Seegmiller,

and Day (1977) explored younger and older adults' spatial encoding using an

intentional-incidental learning paradigm. They found that object locations were

processed without direct instructions to attend to spatial information, suggesting

that location information is automatically encoded. Further, no age differences

emerged. Ellis, Katz, and Williams (1987) found that location encoding did not

change with age after developing in young children (age 3 and 4), suggesting that

this process emerge early and function invariantly throughout the lifetime. These

findings all support the automaticity of location processing.

However, other studies do not support automatic location processing (Naveh-

Benjamin, 1987; Light, & Zelinski, 1983; Jenkins, Myerson, Joerding, & Hale,

2000). Specifically, Naveh-Benjamin (1987) found that intention, aging, training,

competing tasks and individual differences all impacted spatial information

encoding. Light and Zelinski (1983), using an intentional-incidental learning

paradigm, found that instructions also affected location encoding. Age-related

deficits were observed, such that younger adults out-performed older adults in a

variety of visuo-spatial memory tasks (Light & Zelinski, 1983; Jenkins, Myerson,

Joerding, & Hale, 2000; Brockmole, Parra, Della Sala, & Logie, 2008; Brockmole,

& Logie, 2013). Many researchers argued that location encoding might not be

automatic because it declines with age. However, considering that many other

factors, such as reductions of vision or processing speed, and interference from the environment, may also contribute to the age-related deficits found in these studies, the observed age-related differences may reflect these other changes rather than indicating that location information is not automatic encoded.

More recently, some researchers have argued that location information is not automatically encoded, but requires less effort than object encoding (Huang, Treisman, & Pashler, 2007; Thomas, Bonura, Taylor, & Brunyé, 2012; Taylor, Thomas, Artuso, & Eastman, 2014). For example, Taylor et al. (2014) presented participants with grids that contained spatially organized or unorganized objects. They found that spatial organization helped location memory, suggesting that location encoding is not entirely automatic. However, location information was remembered better than object identity information, with or without being spatially organized. This suggested less effortful location encoding. Similarly, Thomas et al. (2012) found that location memory, in both younger and older adults, exceeded identity and combined object-location memory. More interestingly, cognitive load, as operationalized through object array size, only minimally influenced location memory while strongly affecting object and combination memory. These results indicated that although location information may not be automatically encoded, it may be less effortful than object encoding in VSWM processing.

In sum, although the claim that location information is encoded automatically has not been universally supported, evidence supports asymmetric processing demands for VSWM attributes, with fewer resources needed for location processing (Huang, Treisman, & Pashler, 2007; Taylor, Thomas, Artuso, & Eastman, 2014). This asymmetry in cognitive resource demands may also have implications for the interaction and integration of location and object processing. Spatial location information and object identity information compete for cognitive resources in VSWM; the less effortful nature, or reduced requirement for processing resources, of location encoding may lead to greater ease in processing, which may in turn result in relatively better location memory (Thomas, Bonura, Taylor, & Brunyé, 2012; Taylor, Thomas, Artuso, & Eastman, 2014). To better understand the impact of this asymmetry in VSWM processing, here we consider several models relevant to feature or attribute processing.

Before we move on, please note that throughout the paper we will use the term "resource reduction" to refer to the reduction in resource demands associated with a cognitive process. If a process has the characteristic of "resource reduction", it requires fewer cognitive resources for full processing.

Attribute Processing

In the working memory literature, various models have been proposed to explain processing of multiple attributes, such as the *embedded-processes model*

(Cowan, 1988), and the *multiple-component model* (Baddeley & Hitch, 1974).

The latter, as discussed earlier, addresses how multiple attributes of the objects or

items are processed and bound in different working memory components. For

instance, the visuo-spatial sketchpad usually deals with spatial information and

visual identity information on the object level; the phonological loop may be

involved when people linguistically "label" the object, and the episodic buffer has

been proposed to facilitate binding identity and location information (Baddeley,

Allen, & Hitch, 2011).

Other models from the attention literature also address multiple feature

processing. Some of the early models include *feature-integration theory*

(Treisman & Gelade, 1980), the *guided search model* (Wolfe, 1994), and

computational models such as the *race model* (Bundesen, 1987). Here we will

discuss the *race model* as an example, because it fits well with the VSWM studies

discussed in this work. As a computational theory of visual selective attention, the

race models explain how people select targets from multi-element visual displays,

while ignoring distractors (Bundesen, 1987). According to the *race models*, the

selection process involves a "race" between the elements or attributes in the

display toward a final "processed" state (Bundesen, 1987; Shibuya, & Bundesen,

1988; Bundesen, 1990). Items or perceptual categorizations in the display

compete to be selected and processed, and only the items that get to the final state

– a state in which the information is encoded into the short-term memory before

the stimulus presentation ends – will "win" the race (Bundesen, 1987; Bundesen,

1990). In their *fixed-capacity independent race model*, Shibuya and Bundesen

(1988) described a two-stage selection process. In the first stage, for each item or

element in the visual field, a corresponding weight is computed. At the second

stage, a fixed amount of processing capacity is allocated to the items in proportion

to their weights computed in the first stage, and the race begins (Shibuya, &

Bundesen, 1988).

The race model framework could help us understand the interaction between

VSWM features during binding. In VSWM, when spatial location information

and object identity information are both available in the display, they may be

"racing" with each other to get to the final state. Multiple factors may influence

this "race" process. Specifically, factors that have been found to impact VSWM

processing may affect which attribute receives more processing. We will discuss

these influences in detail below.

Factors That Influence VSWM

Previous studies have found several factors that influence visuo-spatial

information processing. As one example, organizing objects into recognizable

spatial configurations helps location memory, but hurts object identity memory

(Taylor, Thomas, Artuso, & Eastman, 2014). In long-term visuo-spatial memory,

semantic associations influence visuo-spatial processing (Hirtle, & Mascolo, 1986;

Merrill, & Baird, 1987; Maddox, Rapp, Brion, & Taylor, 2008). For instance,

Merrill and Baird (1987) found that participants used semantic hierarchies when

recalling map information. Memory for spatial locations, in addition, can be

biased by social categories. Maddox, Rapp, Brion, and Taylor (2008) had

participants learn business locations from a map. Each location was paired with

social information about the owner, specifically his race. Later when estimating

distances between businesses, participants judged businesses whose owners

shared the same racial category as being closer together. These findings suggested

that both spatial organization and semantic association could influence memory

for visuo-spatial information.

In addition, strategic processing, usually introduced via explicit instructions

or an orienting task, affects the depth of information processing and memory

performance (Craik, & Lockhart, 1972), sometimes in VSWM studies (Light, &

Zelinski, 1983). For example, Pezdek and Evans (1979) gave participants

instructions that targeted specific VSWM processing, and found that explicit

instructions affected recognition performances for identities and locations (Pezdek,

& Evans, 1979). It is possible that when given specific instructions, participants

can strategically separate location information from object information and more

exclusively focus on the information needed. This could in turn affect memory

performance.

Age-related changes in cognition also impact visuo-spatial information processing. Thomas and colleagues (2012) found that older adults demonstrated age-related deficits in VSWM, especially in memory for object-location binding. Specifically, when study time was equated, older adults performed worse than younger adults on location trials, object trials, and trials that test combined object-location information. However, when older adults had more time to study, age differences disappeared in object memory and location memory tested alone. Deficits in memory for object-location binding remained even when older adults had additional study time (Thomas, Bonura, Taylor, & Brunyé, 2012).

The aforementioned factors (spatial organization, semantic association, strategic processing, and age) have also been shown to interact with each other in verbal and spatial learning studies. For instance, older adults demonstrated an over-reliance on semantic relatedness leading to increased false memory in list-learning tasks (Thomas, & Sommers, 2005). More recently, Thomas, Bonura, Taylor, and Brunyé (2012) studied how semantic categories affected map memory as a function of age. They found that semantic relatedness biased both older and younger adults' memory. However, younger adults were likely to spatially organize map information, whereas older adults seemed to need explicit instructions to encode and use spatial and semantic information.

In addition, normal aging may interact with strategic processing, and influence the encoding and binding of the VSWM attributes. Consider previous findings that older adults tend to over-rely on semantic information processing while demonstrating declines in location processing, and that younger adults were more likely, than older adults, to spatially organize maps. It is possible that the processing mechanisms associated with spatial and identity information may change as a function of age. Younger and older adults may allocate cognitive resources differently to location and object encoding, and in turn process these attributes in different ways.

In sum, spatial organization, semantic association, strategic processing, age, and their interactions affect processing of VSWM components in different memory tasks. These factors could also influence how individual VSWM attributes are processed and bound. For instance, spatially organizing objects may emphasize location processing and reduce the resources needed to encode location information. Likewise, semantic associations may highlight object processing and result in a resource reduction for object processing.

Factors influencing object-location binding, however, are more complicated. For object-location binding to be successful, both object identity information and corresponding location information should be fully processed. Memory errors happen if either attribute fails to be encoded, or when multiple encoded attributes

are incorrectly integrated. Resource demands of a given task can influence both

individual attribute encoding and multiple attributes integration. Reducing

resource demands through spatial organizations or semantic associations may

result in gist extraction. Participants will notice the organizational relationships

and are likely to spend less time encoding individual item or location, when such

relationship exists. This could be beneficial to the combination memory, but may

also yield gist-consistent false alarms. Specifically, both spatial and semantic

relationships should facilitate combination memory, as they could reduce the

resources needed for individual attribute processing, leaving resources available

for the binding; however, participants may overly rely on spatial and semantic

relationships that processing at the item level may be superficial. For instance,

participants may remember locations in an organized array, but may not have

sufficiently processed objects. Thus, spatial organization and semantic association

may also result in increased false alarms on the combination trials.

In sum, as discussed above, factors that have been found to impact VSWM

individual attribute processing may also affect memory for object-location

binding. The present work extends previous literature by systematically

manipulating these factors in a VSWM paradigm, exploring how these factors

affect VSWM attributes processing.

The Present Study

Using both older and younger adults, the present study examines how spatial

organization, semantic association, strategic processing, and aging affect the

individual encoding and binding between location processing and object

processing in VSWM. Spatial organization should facilitate location processing,

whereas semantic organization should impact object identity processing. We

predicted that spatially organizing objects would increase spatial information

saliency, reducing resource requirements, and in turn improve spatial memory.

Likewise, having semantically associated objects would make object identity

information more salient. Participants should remember object information better

when the objects are associated. Memory for object-location binding should be

affected by spatial organization and semantic association, both positively and

negatively.

To foster strategic processing, trials were blocked by types. "Type" was

defined differently in different experiments, notably by the type of memory tested,

by spatial organization, and by semantic association, in Experiment 2, 3, and 4,

respectively. When blocking trials by the type of memory tested (Experiment 2),

participants knew what they would be tested on in each block. They were

indirectly encouraged to focus on and strategically encode the specific

information tested. Emphasizing location (Experiment 3) or semantic information

(Experiment 4) through blocking, could also make the corresponding information more salient for encoding, and in turn affect individual attribute processing.

To reduce the contributions of age-related general slowing (Salthouse, 1979; Hale, Myerson, & Wagstaff, 1987), older adults were given more time than younger adults to process arrays. We hypothesized that older adults would rely more on object identity processing as compared with spatial location processing, whereas younger adults may be more likely to rely on location processing as compared with object processing in VSWM.

The present work includes four experiments. Experiment 1 is considered a baseline performance experiment, where strategic processing was limited by randomly assessing location information, object information, or object-location binding. In Experiment 2, trials were blocked by question type (location, object, and combination question), thereby indirectly encouraging a strategy to focus only on grid information that was being tested in a given question block. In Experiments 3 and 4, trials were blocked by spatial organization and semantic association, respectively, to accentuate spatial or semantic relationships. We hypothesized that accentuating different attributes would affect individual attribute processing. Further, we hypothesized that making spatial or semantic relationships more salient through blocking would differentially affect younger and older adults.

Experiment 1

In Experiment 1, we systematically manipulated spatial organization and semantic association of objects presented within grids. We hypothesized that spatial organization should facilitate location processing, whereas semantic organization should positively impact object identity processing. On combination trials that tested object-location binding, we hypothesized that performance would be facilitated by both spatial organization and semantic association. Finally, we predicted that older adults would rely more on semantic association while younger adults would rely on spatial information on combination trials.

Methods

Participants. Thirty-six younger adults (18 females and 18 males) and thirty-six older adults (26 females and 10 males) participated in this study. Younger adults were undergraduates from Tufts University (aged from 17 to 23, $M = 18.7$, $SD = 1.07$; education $M = 13.65$ years, $SD = 1.23$; vocabulary test $M = 13.39$, $SD = 1.60$) and received course credit for their participation. Older adults (aged between 65 and 84, $M = 72.1$, $SD = 5.99$; education $M = 16.12$ years, $SD = 2.89$; MMSE $M = 28.79$, $SD = 1.67$; vocabulary test $M = 14.44$, $SD = 2.20$) were community dwelling older adults, recruited from an older-participants pool maintained by the Cognitive Aging and Memory Lab, and were paid $15 per hour for participation.

Design. This experiment used a 2 (Spatial Organization: *Organized,*

Unorganized) × 2 (Semantic Association: *Associated, Unassociated*) × 3

(Question Type: *Location, Object, Combination*) × 2 (Age: *Young, Older*) mixed

design, with Spatial Organization, Semantic Association, and Question Type as

the within-subject variables, and Age as the between-subject variable.

*Materials***:** *Items.* The pictured objects used in this study were color line

drawings, mainly drawn from Rossion and Pourtois' (2004 revised) version of the

Snodgrass and Vanderwart (1980) pictures, and were separated into 18 different

categories following Battig and Montague's (1969) category norms for items. To

have 10 objects per category, a small portion of items was carefully selected from

Clker (http://www.clker.com) to match Rossion and Pourtois' pictures on their

color and texture. Because stimuli were drawn from two separate sources, we had

a separate group of 20 participants rated each image and collected normative data

on naming agreement, response latencies, and similarities of the pictures. Based

on the normative data, images from Clker did not differ significantly from images

from Rossion and Pourtois' stimuli pool. See Figure 1 for sample items and study

grids, and see Appendix for a list of all categories and item names.

Grids.   To-be-studied stimuli included 144 5 × 5 grids each containing five

objects displayed in different locations. These five objects could be semantically

associated (in this case all 5 items were drawn from the same category), or they

could be unassociated with each other (in this case the 5 items were drawn from different categories). In half of the grids, items were placed in a spatially organized manner (i.e., the objects were placed in recognizable spatial configurations such as an I, L, b, V, T or a cross, see Figure 1 for an example), in the other half of the grids, items were placed in an unorganized manner (i.e., with no obvious spatial relationship between objects, see Figure 1). Both locations and items shown were relatively equally distributed in all grids.

   Verbal tests and Questionnaires.   Both younger and older participants finished a general vocabulary test (Shipley, 1946), a synonym vocabulary test and an antonym vocabulary test (Wechsler, 1981) before the study. Older adults also completed a Mini-Mental Status Exam (Mini Mental State Exam; Folstein, Folstein, & McHugh, 1975).

   Procedure.   Stimuli were presented on a standard personal computer monitor via E-prime 2.0 software. All participants first gave informed consent. Following this, participants completed a practice session, in which they did one sample trial for each question type. Before practice and again before the experimental trials, participants received instruction that they would "be presented with a series of displays containing various objects in various locations within a grid." The grids appeared at the center of the computer screen (3000 ms for younger adults and 6000 ms for the older adults). Presentation time for each age

group was based on previous research and further established through pilot testing

(see Thomas et al., 2012). After studying a given grid, participants made a

judgment of learning (JOL) prediction. Similar to JOL questions used in Thomas

et al. (2012), participants were asked, "*how likely do you think you would be to*

recognize the information shown in the grid?" Participants responded using a

Likert scale of 1 to 10 (with 1 being "*not likely at all to recognize*" and 10 being

"*extremely likely to recognize*"). Following this, participants made a yes/no

recognition decision for the previous trial.

Recognition trials were constructed so that twenty-five percent of trials

contained correct identity, location, or combination information. The remaining

75% were incorrect lures. We generated this ratio to introduce conservative

recognition responses. In addition, the design allowed us to further study VSWM

by examining how participants false-alarm to different lures.

Among the 144 recognition trials, 32 tested location, 32 tested identity, and

80 tested combined identity and location information. For location tests,

participants were asked, "*Was an object presented in this location in the previous*

grid?" The question was paired with an objectless grid with a single square

highlighted in red. The highlighted section was either a previous-occupied cell

(correct) or a previous-unoccupied cell (incorrect lure). Identity trials asked "*Was*

this object presented in the previous grid?" and were presented with an object,

without the grid context, that was either previously studied (correct) or unstudied

(incorrect). When both location and identity were tested in combination,

participants saw a grid containing an object (either studied or unstudied) in a cell

(either previously occupied or unoccupied) and were asked, "*Was this object*

presented in this location in the previous grid?" Participants were instructed to

press the *yes* ("a") or *no* ("k") key for all responses.

    Location trials had only one lure type, i.e. a cell that had not been occupied

on the previous study trial. Identity trials had two lure types, either an object

semantically related or semantically unrelated to a studied object. Specifically,

when the five studied objects came from the same category, the lure could be

from that category (related lure) or from a different category (unrelated lure).

When the studied objects were from different categories, the lure could relate to

one of the objects (related lure), or completely unrelated to any of the objects

shown (unrelated lure). Five lure types were used with combined identity and

location trials: an old object placed in a new location, a new object (semantically

related) placed in a new location, a new object (unrelated) placed in a new

location, a new object (semantically related) placed in an old location, and a new

object (unrelated) placed in an old location. Examples of lures can be found in

Figure 2. On combination trials, new objects were classified as those not studied

on the previous trial. New locations were classified as those not occupied on the previous trial.

Study-test trials were counterbalanced to insure that majority of study grids were paired with location, identity, and combination test trials. Of the 144 studied grids, 64 study grids were tested with all three conditions. Thirty-two grids were tested in identity and combination trials only, and another set of 32 grids was tested in location and combination trials only. Sixteen grids were only presented in the context of combination test trials. For instance, grid A was paired with a location recognition test in Counterbalance 1, with an identity test in Counterbalance 2, and with a combination test in Counterbalance 3. Identity, location, and combination test trials were randomly presented throughout Experiment 1.

After all experiment trials, participants filled out a general demographic questionnaire. Older adults also completed a mini mental state exam (MMSE). Then they were given a debriefing form and were thanked for their participation.

Results

JOL data were collected but not included here, as this thesis focuses mainly on VSWM.

Memory performance was evaluated by looking at the proportion recognition hits and false alarms (FAs). Recall that older adults had extra study time to reduce

the influence of age-related changes in speed of processing (Hale, Myerson, &

Wagstaff, 1987; Salthouse, 1979) on the present findings, we analyzed recognition

hits and FAs for younger and older adults separately because of this difference in

presentation time.

Recognition hits were defined as the proportion correct in recognition test,

and were analyzed using 2 (Spatial Organization: Organized, Unorganized) × 2

(Semantic Association: Associated, Unassociated) × 3 (Question Type: Location,

Object, Combination) repeated measures ANOVAs for both age groups.

FAs were defined as erroneous report of a lure as being previous studied, and

were analyzed separately by Question Type given that each question type had

different lure types. Repeated measures ANOVAs were conducted for each

question type, with a shared design of 2 (Spatial Organization: Organized,

Unorganized) × 2 (Semantic Association: Associated, Unassociated) × N (Lure

Type, N depends on question type) on false alarms.

Younger adults Hits.   Analyses yielded main effects of Semantic

Association and Spatial Organization [$F(1, 35) = 9.31$, $p = .004$, $\eta p^2 = .21$; $F(1, 35)$

$= 13.62$, $p = .001$, $\eta p^2 = .28$; see Table 1 for means]. Specifically, semantic

association improved recognition accuracy for younger adults (Means: Associated

$= .74$, Unassociated $= .68$). Spatial organization also improved memory (Means:

Organized $= .76$, Unorganized $= .66$). This main effect of spatial organization was

qualified by the interaction between Spatial Organization and Question Type, $F(2,$

$34) = 11.43$, $p < .001$, $\eta p^2 = .40$. Spatial organization only facilitated younger

adults' memory for locations (Means: Organized $= .83$, Unorganized $= .53$, $t(35) =$

5.04, $p < .001$, $d = 1.28$), but not for objects (Means: Organized $= .76$,

Unorganized $= .75$) or object-location combination (Means: Organized $= .68$,

Unorganized $= .68$).

Younger adults False Alarms. For location trials, there was only one type

of lure: a location that was previously unstudied. FAs analysis for location trials

yielded main effects of both Spatial Organization [$F(1,35) = 10.83$, $p = .002$, ηp^2

$= .24$] and Semantic Association [$F(1, 35) = 9.75$, $p = .004$, $\eta p^2 = .22$].

Specifically, participants more often falsely recognized that a location had been

occupied in unorganized ($M = .20$) as opposed to organized ($M = .11$) grids, and

when grids were semantically unassociated ($M = .20$) as opposed to semantically

associated ($M = .12$). In other words, both spatial organization and semantic

association helped younger adults remember studied locations.

For object trials, there were two types of lures: a related lure was

semantically related to one (when the grid objects were unassociated) or all (when

the grid objects were semantically associated) objects, and an unrelated lure was

unrelated to all grids objects. FAs analysis yielded a main effect of Lure Type, $F(1,$

$35) = 23.75$, $p < .001$, $\eta p^2 = .40$. Younger adults false-alarmed more to related (M

= .18) than to unrelated lures (M = .07). We also observed an interaction between

Semantic Association and Lure Type, $F(1, 35)$ = 10.77, p = .002, ηp^2 = .24. Lure

type only mattered when the studied objects had all been semantically associated.

Specifically, on associated grids, younger adults falsely recognized more related

(M = .21) than unrelated lures (M = .04), $t(35)$ = 5.43, p < .001, d = 1.12. If

studied objects had been unassociated, there was no difference in FAs based on

lure type [$t(35)$ = 1.34, p = .188].

Lure types in combination trials were defined by the relationship of the lure

to both the studied object and location. A combination lure could be the same old

object, a related object, or an unrelated object, and could be placed in an old,

studied location or a new, unstudied location. We computed FA rates for each lure

type. Analysis using repeated measures ANOVA revealed main effects of Spatial

Organization [$F(1,35)$ = 17.40, p < .001, ηp^2 = .33], and Lure Type, $F(4, 32)$ =

13.47, p < .001, ηp^2 = .63. Younger adults were more likely to false alarm when

the grids were unorganized (M = .12) than when they were organized (M = .08).

They also false-alarmed more when the lures were constructed with the same, or

semantically related objects (Means: New location old object = .22, New location

related object = .08, Old location Related object = .14, see Table 2 for other

means).

A significant interaction was found between Spatial Organization and Lure

Type, $F(4,32) = 5.23$, $p = .002$, $\eta p^2 = .40$. As illustrated in Figure 3, young

participants were more likely to false alarm on unorganized trials to lures that

consisted of unstudied locations (Mean FAs to new-location-old-object lures:

unorganized = .29, organized = .14, $t(35) = 3.98$, $p < .001$, $d = .74$; mean FAs to

new-location-related-object lures: unorganized = .11, organized = .05, $t(35) =$

3.17, $p = .003$, $d = .46$). The exception was with an unrelated object placed in a

new location, in which case FAs were very low in both organized and unorganized

grids (Means: Organized = .03, Unorganized = .02). Lure Type also interacted

with Semantic Association, $F(4,32) = 4.72$, $p = .004$, $\eta p^2 = .37$. As shown in

Figure 4, semantic association increased participants' FA rates, but only when the

lures were related to the studied objects (Mean FAs to new-location-related-object

lures: unassociated grid = .04, associated grid = .12, $t(35) = 2.40$, $p = .02$, $d = .51$;

mean FAs to old-location-related-object lures: unassociated grid = .09, associated

grid = .19, $t(35) = 3.25$, $p = .003$, $d = .59$). No other lure types showed FA

differences between associated and unassociated grids.

Older Adults Hits. A repeated measures ANOVA on older adults'

recognition accuracy yielded main effects of Spatial Organization, Semantic

Association, and Question Type [$F(1, 35) = 41.85$, $p < .001$, $\eta p^2 = .55$; $F(1, 35) =$

4.52, $p = .04$, $\eta p^2 = .11$; $F(2, 34) = 3.78$, $p = .03$, $\eta p^2 = .18$; see Table 1 for means].

Spatial organization increased hit rates when the grids were organized into spatial

configurations ($M = .74$) compared to when unorganized ($M = .56$). Semantic

association facilitated performance when the objects in the grids were associated

($M = .68$) as compared to unassociated ($M = .62$). In addition, older adults tended

to remember object information better than both location information and

combined information [$t(35) = 2.24$, $p = .03$, $d = .37$; $t(35) = 2.10$, $p = .04$, d

$= .42$]. We also found an interaction between Spatial Organization and Question

Type, $F(2, 34) = 6.57$, $p = .004$, $\eta p^2 = .28$. Spatial organization improved older

adults' memory by increasing hit rates for location memory (Means: Unorganized

$= .48$, Organized $= .76$, $t(35) = 6.07$, $p < .001$, $d = 1.04$ and object information

(Means: Unorganized $= .62$, Organized $= .79$, $t(35) = 3.09$, $p = .004$, $d = .64$), but

not object-location combined information. Older adults demonstrated equal

performances on combination trials when the grids were organized ($M = .66$) and

unorganized ($M = .59$).

Older Adults False Alarms. Similar to the analyses conducted for younger

adults, false alarm rates were also analyzed separately by Question Type. For

older adults, we conducted the same repeated measures ANOVAs for each

question type on false alarms (see Table 2 for means).

On location trials, main effects of both Spatial Organization [$F(1,35) = 11.40$,

$p = .002$, $\eta p^2 = .24$] and Semantic Association [$F(1, 35) = 6.78$, $p = .01$, $\eta p^2 = .16$]

were observed. Specifically, participants falsely recognized unstudied locations

more often when presented with unorganized ($M = .17$) as compared to organized

($M = .10$) grids, and when grids were semantically unassociated ($M = .16$) as

opposed to semantically associated ($M = .12$). Spatial Organization and Semantic

Association also interacted, $F(1, 35) = 7.38$, $p = .01$, $\eta p^2 = .17$. With unorganized

grids, semantic relatedness did not affect performance (Means: Associated = .17,

Unassociated = .17, $t(35) = .17$, $p = .86$), however, with organized grids, older

adults false-alarmed more frequently if studied objects had not been associated

(Means: Associated = .06, Unassociated = .14, $t(35) = 4.59$, $p < .001$, $d = .67$). In

other words, older adults made the fewest FAs to unstudied locations, when they

studied both spatially organized and semantically related information.

On object trials, we found a main effect of Lure Type, $F(1, 35) = 48.56$, p

$< .001$, $\eta p^2 = .58$. Participants made more recognition errors when lures were

related to the studied objects ($M = .22$) than when they were unrelated ($M = .06$).

The interaction between Spatial Organization and Semantic Association was

significant, $F(1, 35) = 11.84$, $p = .002$, $\eta p^2 = .25$. Participants made more FAs on

object memory trials under all other conditions (Means: Organized and associated

= .17, Unorganized and associated = .15, Unorganized and associated = .17), as

compared with when grids were both organized and unassociated ($M = .07$).

Additionally, we observed an interaction between Semantic Association and Lure

Type, $F(1,35) = 25.99$, $p < .001$, $\eta p^2 = .43$. For unassociated grids, participants'

FAs were not affected by Lure Type (Means: Related Lure = .15, Unrelated lure

= .10); however, when the grids had been associated semantically, we observed an

increase in FAs with related lures (M = .29, $t(35)$ = 4.57, $p < .$ 001, d = .77), and a

drop in FAs with unrelated lures (M = .02, $t(35)$ = 2.93, $p = .$ 006, d = .67),

compared with FAs to unassociated grids (Related lure = .15, Unrelated lure

= .10). These FA results for object trials suggested the important influence of

semantic association on older adults' object memory, reducing FAs in some cases,

while increasing FAs in others. Additionally, spatial organization facilitated object

memory by reducing FAs for semantically unassociated objects.

For combination trials, we again computed FA rates for each lure type, and

found main effects of Semantic Association ($F(1, 35)$ = 7.03, $p = .01$, ηp^2 = .17),

and Lure Type, $F(4, 32)$ = 14.67, $p < .001$, ηp^2 = .65. Older adults were more

likely to false alarm when the grids were associated (M = .10) compared to when

they were unassociated (M = .07). They also false-alarmed more when the lures

were the same or related to studied objects (Means: New location Old object = .19,

Old location Related object = .12; see Table 2 for other means). A significant

interaction was found between Semantic Association and Lure Type, $F(4,32)$ =

6.52, $p = .001$, ηp^2 = .45. As illustrated in Figure 4, semantic association did not

affect older adults' performance except for one lure type: with the

old-location-related-object lures, participants made more FAs on semantically

associated grids (M = .21) than on unassociated grids (M = .03, $t(35)$ = 5.20, p <.

001, d = 1.13). These results suggest that although older adults are able to use

semantic associations to facilitate their memory, they might be more likely to rely

on, or even be biased by semantic association when remembering object locations

and identities, as seen in the increased FAs.

Discussion

Experiment 1 explored whether spatial organization and semantic association

affect younger and older adults' VSWM differently. In the present experiment,

participants were not informed as to which attribute or combination of attributes

would be tested on a given trial.

We found that spatial organization and semantic association manipulations

both influenced individual VSWM attribute processing, but in different ways

depending on participants' age and the type of information tested. Specifically,

spatial organization facilitated younger adults' memory accuracy on location trials

only; however, it facilitated older adult performance on both location and object

trials. In addition, semantic association only improved younger adults' accuracy

on object memory, whereas it benefited older adults' accuracy on both object

memory and combination memory.

Spatial and semantic relationships also affected younger and older adults'

memory errors in different ways. For example, younger adults used spatial

organizations more efficiently than semantic associations to reject lures in

combination trials. More specifically, we found that spatial organization

facilitated younger adults' performance on combination trials by reducing false

alarms, whereas semantic associations resulted in slightly more combination false

alarms. For older adults, however, neither spatial organization nor semantic

association reduced memory errors on object-location binding. Compared with

their younger counterparts, older adults might be less efficient in using spatial

relationships to reject lures in object-location binding. In addition, semantic

association negatively affected older adults' performance on combination trials by

causing more memory errors, suggesting that semantic associations may bias

older adults' memory for object-location binding.

In Experiment 1, we hypothesized that without knowing what information

would be tested, younger and older adults might differentially process location

and object information. Specifically, younger adults would be more influenced by

spatial organization whereas older adults would be more affected by semantic

associations. Consistent with this hypothesis, we found that younger adults used

spatial organizations more than semantic associations, whereas semantic

associations impacted older adults to a greater extent, both positively and

negatively. These results suggest differential processing of VSWM components

and influences of manipulations of these components as a function of age.

Still an open question is the role strategic processing might play. In

Experiment 1, participants could not predict what information would be tested and

therefore could not be strategic. Considering the finding that older adults may

need explicit instructions to effectively process visuo-spatial information (Thomas,

Bonura, & Taylor, 2012), it is possible that this age-related deficit in strategy use

may contribute to our finding that younger and older adults apply spatial

organization and semantic association differently. Experiment 2 addressed this

possibility, blocking trials by question types so that participants knew what would

be tested and could strategically process that information.

Experiment 2

Experiment 2 further investigated the effects of spatial organization and

semantic association on VSWM, here allowing strategic processing. Trials were

blocked by question type, allowing for strategy shifts related to the information

tested.

We hypothesized that when participants could strategically encode grid

information, they would demonstrate better VSWM overall. Additionally, spatial

organization should only benefit location processing; semantic association,

similarly, should facilitate object memory only. On combination trials, we

hypothesized that semantic association would affect older adults more while

spatial organization would influence younger adults VSWM processing more.

Methods

Participants. A total of fifty-one participants took part in this experiment, in

which twenty-six were younger adults (12 females and 14 males) and twenty-five

were older adults (20 females and 5 males). Younger adults recruited from Tufts

University were undergraduates aged from 18 to 28 (age $M = 19.38$, $SD = 1.12$;

education $M = 14.48$ years, $SD = 1.21$; vocabulary test $M = 13.46$, $SD = 1.68$) and

were given course credit for their participation. Older adults (aged between 60

and 93, $M = 73.72$, $SD = 7.84$; education $M = 16.78$ years, $SD = 3.03$; MMSE $M =$

29.10, $SD = 1.51$; vocabulary test $M = 14.64$, $SD = 2.16$) were community

dwelling older adults, recruited from an older participants pool maintained by the

Cognitive Aging and Memory Lab. They were paid $15 per hour for participation.

Design. The design and materials used in Experiment 2 were the same to

those in Experiment 1.

Procedure.   Experiment 2 has a similar procedure to Experiment 1, except

that instead of randomizing all trials, recognition tests with the same type of

questions were blocked in Experiment 2. Participants completed a practice section

in which they did two sample-recognition tests in each question type. Then they

completed a block of location trials, a block of identity trials, and a block of

combination trials. The order of blocks was counterbalanced. Each block begun

with a detailed instruction, as to which kind of information participants should

pay attention to in this block, followed by a series of trials asking the same

questions. For instance, participants were instructed to "*remember what locations*

the objects are presented" in location block, and to "*remember what objects are*

presented" in identity block; in combination block they were asked to "*remember*

what objects are presented as well as what locations the objects are presented".

Trials were identical to Experiment 1, except that all JOL questions in Experiment

2 targeted specific grid information. For example, in location block, the JOL

questions were "*how likely do you think you are to remember the locations of the*

objects in the previous grid?"; in identity block, the JOL questions were "*how*

likely do you think you are to remember the objects shown in the previous grid?";

and in combination block, the JOL questions were "*how likely do you think you*

are to remember the objects and the locations they were placed in the previous

grid?".

Results

Similar to Experiment 1 analyses, recognition hits and FAs were analyzed

separately for younger and older adults. The design for analyses matched

Experiment 1.

Younger adults Hits. A repeated measures ANOVA yielded main effects of

Semantic Association and Question Type [$F(1, 25) = 7.05$, $p = .014$, $\eta p^2 = .22$;

$F(2, 24) = 8.80$, $p = .001$, $\eta p^2 = .42$]. Semantic association improved younger

adults' recognition performance overall (Means: Associated= .79,

Unassociated= .71). In addition, younger adults more accurately recognized

studied locations (M = .80) and objects (M = .81), than they did with the

object-location combinations (M = .65). The interaction between Spatial

Organization and Question Type was significant, $F(2, 24) = 7.90$, $p =.004$, ηp^2

= .37. Spatial organization only benefited younger adults' hits for locations

(Means: Organized = .89, Unorganized = .70, $t(25) = 3.43$, $p = .002$, $d = .93$), but

not for objects (Means: Organized = .79, Unorganized = .83) or object-location

combination (Means: Organized = .67, Unorganized = .62).

Younger adults False Alarms. FAs analysis for location trials yielded a

main effect of Spatial Organization [$F(1,25) = 52.58$, $p < .001$, $\eta p^2 = .68$]. Young

participants false-alarmed more with organized grids (M = .17) as compared to

organized ones (M = .04). In addition, unlike Experiment 1, semantic association

did not reduce FAs, thus showing no benefits on location memory.

For object trials, FAs analysis yielded a main effect of Lure Type, $F(1, 25) =$

5.09, $p = .03$, $\eta p^2 = .17$. Specifically, Younger adults false-alarmed more to

associated (M = .10) than to unassociated lures (M = .05). An interaction between

Semantic Association and Lure Type was also found, $F(1, 25) = 9.91$, $p = .004$,

$\eta p^2 = .28$. Lure type only influenced participants' FAs when objects were related.

Specifically, when grids were associated, younger adults false-alarmed more to

related ($M = .14$) than unrelated lures ($M = .01$), $t(25) = 4.54$, $p < .001$, $d = 1.17$.

If grids were unassociated, lure type did not affect object FAs.

   On combination trials, analyses revealed main effects of Spatial Organization

[$F(1,25) = 4.51$, $p = .04$, $\eta p^2 = .15$], and Lure Type, $F(4, 22) = 8.24$, $p < .001$, ηp^2

$= .60$. Spatial organization reduced younger adults' FAs on combination trials,

resulting in more FAs when the grids were unorganized ($M = .11$) as opposed to

when organized ($M = .08$). Additionally, more FAs were observed when the lures

were the same or related to studied objects (Means: New location Old object $= .18$,

New location Related object $= .08$, Old location Related object $= .14$, see Table 4

for other means). We also found a significant interaction between Spatial

Organization and Lure Type, $F(4,22) = 5.27$, $p = .004$, $\eta p^2 = .49$. As Figure 5

illustrates, spatial organization reduced young participants' FAs, but only when

lures were old objects appearing in new locations (Means: Unorganized $= .25$,

Organized $= .11$, $t(25) = 3.13$, $p = .005$, $d = .84$). No other lure types showed FA

differences between organized and unorganized grids. Additionally, unlike

Experiment 1, semantic association did not affect younger adults' FAs on

combination trials.

   Older Adults Hits. A repeated measures ANOVA yielded main effects of

Semantic Association, and Spatial Organization [$F(1, 25) = 8.11$, $p = .009$, ηp^2

$= .25$; $F(1, 24) = 12.85$, $p = .001$, $\eta p^2 = .35$]. Semantic association increased older

adults' hit rates when the grids were associated ($M = .71$) as compared to

unassociated ($M = .61$). Spatial organization ($M = .72$) also improved older adults'

overall memory compared to unorganized grids ($M = .60$). However, this main

effect of Spatial Organization was qualified by an interaction between Spatial

Organization and Question Type, $F(2, 23) = 9.02$, $p = .001$, $\eta p^2 = .44$. Spatial

organization only improved older adults' memory for location (Means: Organized

= .76, Unorganized = .47, $t(24) = 4.53$, $p < .001$, $d = .93$), but not for object

(Means: Organized = .72, Unorganized = .67) and object-location combined

(Means: Organized = .67, Unorganized = .67).

Older Adults False Alarms. On location trials, we observed a main effect of

Spatial Organization [$F(1,24) = 12.18$, $p = .002$, $\eta p^2 = .34$]. Spatial organization

benefited older adults' memory by reducing FAs on location trials (Means:

Unorganized = .12, organized = .04). Unlike Experiment 1, semantic association

did not reduce location FAs; FAs were equally low with both associated and

unassociated grids.

On object trials, we found a main effect of Spatial Organization, $F(1, 24) =$

8.46, $p = .008$, $\eta p^2 = .26$. Instead of facilitating memory for object information,

spatial organization hurt older adults' object memory by increasing FAs with

organized grids (Means: Organized = .07, Unorganized = .03). In addition, Spatial

Organization interacted with Semantic Association [$F(1, 24) = 8.52$, $p = .008$, ηp^2

= .26]. For unassociated grids, spatial organization did not affect FAs for object

memory (Means: Organized = .04, Unorganized = .03); however, when studied

objects were semantically associated, participants false-alarmed more after

studying organized (M = .11) compared to unorganized grids (M = .03), $t(24)$ =

4.44, $p < .001$, d = 1.02. Another significant interaction was observed between

Spatial Organization and Lure Type, $F(1,24) = 8.52$, $p = .008$, $\eta p^2 = .26$. With

unorganized grids, there was no difference between participants' FAs to

unassociated (M = .02) and unassociated lures (M = .04), however, with organized

grids, older adults false-alarmed more to associated lures (M = .10) than to

unassociated lures (M = .04), $t(24) = 2.57$, $p = .02$, d = .65. Meanwhile, Semantic

Association and Lure Type also interacted, $F(1,24) = 12.77$, $p = .002$, $\eta p^2 = .35$.

Lure type influenced participants' FAs differently. Specifically, when grids were

associated, older adults false-alarmed more to related (M = .11) than unrelated

lures (M = .03), $t(24) = 3.16$, $p = .004$, d = .89; however, when grids were

unassociated, we found the opposite pattern: participants made more FAs to

unrelated (M = .06) than related lures (M = .01), $t(24) = 2.28$, $p = .03$, d = .60.

These object FA results suggested that, unlike Experiment 1, when strategic

processing was introduced through blocking, older adults' memory for object

information was in fact hurt by spatial organization, resulting in more FAs on

object trials when the grids were organized. Meanwhile, semantic association

within the grids did not influence older adults' object memory, which was inconsistent with our previous hypothesis.

For combination trials, we found main effects of Spatial Organization [$F(1, 24) = 5.77$, $p = .024$, $\eta p^2 = .19$], and Lure Type, $F(4, 21) = 11.09$, $p < .001$, $\eta p^2 = .68$. More specifically, spatial organization improved older adults' memory for object-location binding by reducing FAs on combination trials (Means: Unorganized $= .10$, Organized $= .07$). Participants also false alarmed more when the lures were the same or related to studied objects (Means: New location Old object $= .18$, Old location Related object $= .14$), see Table 4 for other means. Additionally, a significant interaction was found between Spatial Organization and Semantic Association, $F(1,24) = 4.32$, $p = .048$, $\eta p^2 = .15$. Specifically, spatial organization reduced older participants' FAs only when objects were semantically associated. When the grids were associated, older adults false-alarmed more on unorganized grids ($M = .11$) than on organized grids ($M = .06$), $t(24) = 3.27$, $p = .003$, $d = .66$. No such difference was observed with unassociated grids. Semantic relatedness did not affect performance on any other lure type.

Discussion

Experiment 2 showed that in the context of strategic processing, spatial organization facilitated both younger and older adults' memory accuracy on location trials; semantic association, however, improved younger adults' accuracy

on object memory, while benefitting older adults on combination memory. In addition, we hypothesized that when participants could strategically process grid information, they would demonstrate better VSWM overall, comparing with when tested randomly on different information. We found that strategic processing yielded a memory advantage in younger adults but not in older adults. Specifically, younger adults demonstrated better location memory in Experiment 2 ($M = .80$), than in Experiment 1 ($M = .68$), $t(60) = 3.00$, $p = .006$, $d = .77$. Older adults, however, demonstrated limited effect of strategic processing on location memory, suggesting that they may be less efficient than younger adults in extracting a useful strategy from the experimental design to remember location information. We also found an interaction between semantic association and strategic processing in combination memory. The bias on object-location binding caused by semantic association disappeared when strategic processing was possible, indicating an effect of strategic processing on reducing bias.

As suggested by the results of Experiments 1 and 2, spatial organization, semantic association, strategic processing and aging all affected VSWM. Our finding that location memory could be improved by spatial organization and strategic processing indicates that location processing may not meet the criteria as an automatic process (Hasher, & Zacks, 1979), and that location information may not be automatically encoded in VSWM. In addition, with strategic processing,

participants from different age groups demonstrated different patterns in their

VSWM performances. For instance, younger adults benefited from strategically

processing, demonstrating improved location accuracy and reduced combination

false alarms, whereas older adults showed limited effect of strategic processing,

demonstrating reduced combination false alarms only. Consistent with previous

literature, our finding suggests that strategy use in older adults may be less

effective comparing with younger adults. Older adults were less able to take

advantage of spatial and semantic relationships even when strategic processing

was introduced. However, it is possible that with trials blocked by question types,

the spatial and semantic relationships may not have been salient enough for older

participants. To address this possibility, we blocked trials by spatial organization

and semantic association respectively, to indirectly encourage different VSWM

attributes in Experiments 3 and 4.

Experiment 3

Experiment 3 addressed the possibility that spatial organization might not be

salient enough for older adults to use efficiently. We indirectly encouraged

location processing by blocking trials by spatial organization. Participants

completed two blocks of trials in a counterbalanced order. Half of the participants

received a block of unorganized grids first, followed by an organized block; the

other half saw organized grids first, followed by an unorganized block. Using this

blocked design we were able to examine whether making location information more salient would affect VSWM. We hypothesized that blocking by spatial organization would make location information more salient, and would in turn facilitate spatial processing for both younger and older adults. However, accentuating spatial information should have a greater impact on older adults, as they might need extra instructions or environmental support to use strategies effectively at encoding.

Methods

Participants. Sixty-three participants took part in this experiment, in which thirty-four were younger adults (27 females and 7 males) and twenty-nine were older adults (27 females and 2 males). Younger adults recruited from Tufts University were undergraduates aged from 18 to 21 ($M = 18.62$, $SD = .82$; education $M = 13.65$ years, $SD = 1.22$; vocabulary test $M = 13.26$, $SD = 1.77$) and were given course credit for their participation. Older adults (aged between 58 and 79, $M = 68.20$, $SD = 5.40$; education $M = 17.58$ years, $SD = 2.27$; MMSE $M = 29.03$, $SD = 1.07$; vocabulary test $M = 15.00$, $SD = 1.69$) were community dwelling older adults, recruited from an older-participants pool maintained by the Cognitive Aging and Memory Lab. They were paid $15 per hour for participation.

Design. The design and materials used in Experiment 3 were the same to those in Experiment 2.

Procedure.   Experiment 3 had a similar procedure to Experiment 1, except

that the studied grids were blocked by spatial organization. Question types and

Semantic associations were randomized. Participants completed a practice section

in which they did two sample-recognition tests in each question type. Then they

completed a block of organized trials, and a block of unorganized trials. The order

of blocks was counterbalanced, so half of the participants did spatially organized

trials first and the other half did the unorganized ones first. No specific

instructions on what to expect at test were given. The JOL questions were the

same with those used in Experiment 1.

Results

In Experiment 3, recognition hits and FAs were also analyzed separately for

younger and older adults. The analyses matched Experiment 1 with the addition

of a 2-level between-subject factor "Order (Organized first, Unorganized first)".

Younger adults Hits. A repeated measures ANOVA yielded a main effect of

Semantic Association, $F(1, 32) = 11.27$, $p = .002$, $\eta p^2 = .26$. Semantic association

improved younger adults' recognition performance in general (Means:

Associated= .73, Unassociated= .65). We also found that Spatial Organization

interacted with Order, $F(1, 32) = 6.80$, $p = .014$, $\eta p^2 = .18$. Participants who

completed organized trials first demonstrated equal memory accuracy with the

organized ($M = .69$) and unorganized ($M = .71$) grids; however, those who did

unorganized trials first performed better when the grids were organized (M = .75)

than when unorganized (M = .62).

Younger adults False Alarms. Analyses yielded main effects of Spatial

Organization and Semantic Association [$F(1,32) = 36.15$, $p <.001$, $\eta p^2 = .54$;

$F(1,32) = 4.69$, $p = .038$, $\eta p^2 = .13$]. Both spatial organization and semantic

association facilitated younger adults' location memory by reducing FAs.

Specifically, young participants made more false alarms when the grids were

unorganized (M = .28) than organized (M = .11); they also false alarmed more

when the studied objects were not associated semantically (M = .23) as compared

with associated grids (M = .16).

FAs analysis on object trials yielded a main effect of Lure Type, $F(1, 32) =$

16.70, $p < .001$, $\eta p^2 = .34$. Younger adults made more false alarms to related (M

$= .14$) than to unrelated lures ($M = .06$). We also observed an interaction between

Semantic Association and Lure Type, $F(1, 32) = 4.21$, $p = .049$, $\eta p^2 = .12$. Lure

types affected participants' FAs, but only when the studied objects were

associated semantically. Specifically, when grids were associated, younger adults

false alarmed more to related lures ($M = .15$) than unrelated lures ($M = .05$), $t(33)$

$= 3.63$, $p < .001$, $d = .87$. No difference was found in FAs across different lure

types (Means: Related lure= .07, Unrelated lure = .10). In addition, Lure Type and

Order interacted, $F(1, 32) = 4.50$, $p = .042$, $\eta p^2 = .12$. Lure types only affected

participants who did the organized trials first. Participants who finished organized

trials first were more likely to false alarm to related lures ($M = .18$) as compared

with unrelated lures ($M = .05$), $t(18) = 4.92$, $p < .001$, $d = 1.15$; whereas those

who completed unorganized trials first did not differ in their FA rates to related

and unrelated lures (Means: Related lure = .11, Unrelated lure = .07).

On combination trials, repeated measures ANOVA revealed main effects of

Spatial Organization [$F(1,32) = 5.60$, $p = .024$, $\eta p^2 = .15$], and Lure Type [$F(4, 29)$

$= 11.93$, $p < .001$, $\eta p^2 = .62$]. Spatial organization benefited younger adults'

memory for object-location binding by reducing FAs (Means: Unorganized = .11,

Organized = .08). Additionally, participants made more FAs when the lures were

same or related to studied objects (Means: New location Old object = .19, New

location Related object = .09, Old location Related object = .14, see Table 6 for

other means).

We also observed an interaction between Semantic Association and Lure

Type, $F(4,29) = 4.00$, $p = .011$, $\eta p^2 = .36$. As can be seen in Figure 8, young

participants falsely recognized significantly more related lures, namely

new-location-related-object lures and old-location-related-object lures, when the

grids were associated as compared to when unassociated [$t(33) = 2.39$, $p = .02$, d

$= .55$; $t(33) = 2.14$, $p = .04$, $d = .54$].

These findings suggested that, when indirectly encouraging location

processing through blocking, the benefit of the emphasized location information,

found in Experiment 1 and 2, were greatly reduced. Spatial organization here did

not benefit younger adults as much as in Experiment 1. Block order mattered: the

organized-first group outperformed the unorganized-first group on unorganized

grids. The organized-first group performed equally well on the organized and

unorganized block, whereas the unorganized-first group demonstrated worse

performance on the unorganized block. It was possible that participants who did

the organized block first benefited from a carry-over effect from the presence of

spatial organization in the first block, and tried to impose similar organizations

with the unorganized grids in the second block.

Older Adults Hits. A repeated measures ANOVA yielded main effects of

Semantic Association, and Question type [$F(1, 28) = 5.16$, $p = .031$, $\eta p^2 = .16$;

$F(1, 28) = 6.01$, $p = .007$, $\eta p^2 = .31$]. Overall, semantic association improved

older participants' hit rates (Means: Associated = .70, Unassociated = .63). In

terms of question type, older adults tended to be more accurate on object memory

($M = .74$) than on either location ($M = .60$) or combination memory ($M = .65$).

Several significant interactions were found. Specifically, spatial organization

and semantic association interacted, $F(1, 28) = 10.11$, $p = .004$, $\eta p^2 = .27$. Older

adults were most accurate when spatial and semantic relationships were both

present ($M = .77$); they performed at similar levels when only one type or neither

type of relationship existed (Means: Organized and unrelated = .63, Unorganized

and related = .63, Unorganized and unrelated = .62). In addition, Spatial

Organization and Question Type interacted [$F(2, 27) = 6.22$, $p = .005$, $\eta p^2 = .32$].

Spatial Organization facilitated older adults' performance on location trials

(Means: Organized= .72, Unorganized= .48; $t(29) = 3.06$, $p = .005$, $d = .64$), but

not on object (Means: Organized = .73, Unorganized = .75) or combination

memory (Means: Organized = .65, Unorganized = .65). Semantic Association also

interacted with Question Type [$F(2, 27) = 5.20$, $p = .012$, $\eta p^2 = .28$]. Semantic

association resulted in better performance on both object and combination

memory, but not on location memory. Specifically, older participants recognized

object information more accurately with associated ($M = .81$) than unassociated

grids ($M = .67$), $t(29) = 2.29$, $p = .03$, $d = .58$; they were also more accurate on

combination trials when grids were associated ($M = .72$) than associated ($M = .58$),

$t(29) = 3.55$, $p = .001$, $d = .64$. No such difference was found on location trials.

Older Adults False Alarms. On location trials, a main effect of Spatial

Organization was observed [$F(1,28) = 9.92$, $p = .004$, $\eta p^2 = .26$]. Spatial

organization benefited older adults' location memory by reducing FAs (Means:

Unorganized = .19, Organized = .08)

Repeated measures ANOVA on object FAs yielded a main effect of Lure

Type, $F(1, 28) = 20.57$, $p < .001$, $\eta p^2 = .42$. Similar to Experiment 1, older adults

false-alarmed more to lures that were related to the studied objects ($M = .14$) as

compared with unrelated lures ($M = .06$). In addition, we found a significant

interaction between Spatial Organization and Semantic Association, $F(1, 28) =$

12.11, $p = .002$, $\eta p^2 = .30$. For associated grids spatial organization did not affect

false alarms for object memory (Means: Organized = .16, Unorganized = .12);

however, when studied objects were unrelated, participants false-alarmed more

when the grids were spatially unorganized (Means: Unorganized = .14, Organized

= .07; $t(29) = 2.03$, $p = .01$, $d = .49$). Additionally, Semantic Association and Lure

Type interacted, $F(1,28) = 12.14$, $p = .002$, $\eta p^2 = .30$. Related lures resulted in

more FAs on associated grids ($M = .24$), compared to unassociated grids ($M = .03$),

$t(29) = 2.88$, $p = . 007$, $d = .58$; however, with unrelated lures, FAs to associated

grids ($M = .13$) did not differ from those to unassociated grids ($M = .08$).

For combination trials, we found main effects of Spatial Organization [$F(1,$

$28) = 9.36$, $p = .005$, $\eta p^2 = .19$], Semantic Association [$F(1, 28) = 19.77$, $p < .001$,

$\eta p^2 = .41$, and Lure Type [$F(4, 25) = 9.90$, $p < .001$, $\eta p^2 = .61$]. More specifically,

spatial organization facilitated older adults' combination memory by reducing FAs

(Means: Unorganized = .12, Organized = .08). In contrast, semantic association

increased FAs on combination trials (Means: Unassociated = .07, Associated

= .13). Lure types also affected older adults' FAs. Older adults false-alarmed more

when the lures were old or related to studied objects (Means: New location Old

object = .26, Old location Related object = .12; see Table 6 for all means).

In addition, significant interactions were found between Spatial Organization and Lure type, $F\,(4,25) = 9.19$, $p < .001$, $\eta p^2 = .60$. As Figure 7 illustrated, spatial organization reduced older adults' FAs on combination trials, but only when the lures were placed in new unstudied locations. Specifically, older adults were more likely to falsely recognize a new-location-old- object lure, when the grids were unorganized ($M = .34$), as opposed to when organized ($M = .18$); similarly, they were more likely to false-alarm to a new-location-related-object lure, when the grids were unorganized ($M = .11$), as opposed to when organized ($M = .04$).

Another significant interaction was found between Semantic Association and Lure Type [$F(4,25) = 4.65$, $p = .006$, $\eta p^2 = .43$]. As illustrated in Figure 8, older adults tended to be biased by the semantic associations of the grids, but only when the lures were related to the studied objects. Specifically, they were more likely to falsely recognize new-location-related-object lures when grids were semantically associated ($M = .12$) than when unassociated ($M = .03$), $t(29) = 3.08$, $p =. 005$, $d = .61$; they were also more likely to false alarm to old-location-related-object lures with associated ($M = .22$) than unassociated grids ($M = .07$), $t(29) = 3.35$, $p =. 002$, $d = .80$. Semantic association did not affect performance on any other lure type.

Discussion

We predicted that blocking by spatial organization would make location information more salient and would in turn facilitate location processing for both younger and older adults. Partly consistent with this prediction, we found that indirectly emphasizing spatial relationships by trial-blocking facilitated location processing for younger adults when no such relationship was presented. Specifically, for younger adults, blocking by spatial relationships reduced the benefit of spatial organization on location memory. Nonetheless, the effect was reduced because blocking improved younger adults' performance on the spatially unorganized trials, as compared with Experiment 1, demonstrating a facilitative effect of blocking on location memory. Older adults, however, did now show such patterns. For them, indirectly emphasizing spatial processing through blocking did not affect the positive effect of spatial organization on location memory, showing limited benefit from blocking.

In Experiment 3, each participant completed a block of organized grids, and a block of unorganized grids. The order of these two blocks should matter. When the unorganized block was given first, participants did not have spatial organization as a contrast and may not spontaneously try to impose their own organizations on the presented objects. However, when the organized block was given first, participants might try to apply the same rule by imposing spatial

organizations on the unorganized objects. Here, we found the predicted results,

but only in younger adults. With the organized block first, participants might have

benefited from a transfer effect that was carried over from the first block, where

grids were organized spatially, to the second, unorganized block. This finding fits

with an idea suggested by Thomas et al. (2012). Thomas and colleagues (2012)

found that recognition accuracy for location trials dropped when the array size

increased from 2 to 3 (likely because of the increased cognitive load), but

surprisingly remained stable when the array size went from 3 to 5 (which should

require more cognitive load). One possible explanation for this stability could be

that, even though no identifiable spatial configuration was presented in the study

grids, participants might have generated spatial relationships from the objects to

strategically remember spatial locations.

However, we should note that this transfer effect when blocking trials by

spatial organization was only evident for younger adults, but not older adults.

Older adults may be less inclined to spontaneously impose, or less efficient in

using spatial organization. Experiment 4 explores an aspect of VSWM that older

adults do use in memory, semantic association (Thomas, & Sommers, 2005;

Thomas, Bonura, Taylor, & Brunyé, 2012).

Experiment 4

In Experiment 4, we blocked trials by semantic association to indirectly

encourage object processing. Participants completed two blocks, one with all

semantically associated grids and the other with all semantically unassociated

grids. Block order was counterbalanced. Half of the participants received

associated grids first, followed by an unassociated block; the other half received

the blocks in the reverse order. Using this design, we could examine whether

making object information more salient would affect VSWM. We hypothesized

that accentuating semantic relatedness would provide additional environment

support to facilitate object processing for older adults. However, making object

information more salient could also benefit young adults, as they were shown in

previous literature to rely less on object than on location processing in VSWM.

Methods

Participants. A total of sixty participants took part in Experiment 4. Thirty

were younger adults (13 females and 17 males) and the rest thirty were older

adults (25 females and 5 males). Younger adults recruited from Tufts University

were undergraduates aged from 18 to 22 ($M = 18.97$, $SD = 1.03$; education $M =$

13.73 years, $SD = 1.25$; vocabulary test $M = 12.93$, $SD = 1.87$) and were given

course credit for their participation. Older adults (aged between 56 and 74, $M =$

68.43, $SD = 4.51$; education $M = 16.7$ years, $SD = 3.60$; MMSE $M = 29.06$, $SD =$

1.34; vocabulary test $M = 14.50$, $SD = 2.13$) were community dwelling older

adults, recruited from an older-participants pool maintained by the Cognitive

Aging and Memory Lab. They were paid $15 per hour for participation.

Design.   The design and materials used in Experiment 4 were the same to

those in Experiment 3.

Procedure.   Experiment 4 had a similar procedure to Experiment 3, except

that in this experiment, trials were blocked by semantic association of the grids.

Question types and spatial organizations were randomized. After the practice

session, participants completed a block of associated trials, and a block of

unassociated trials. The order of blocks was counterbalanced, so half of the

participants did the associated trials first and the other half did the unassociated

ones first. No specific instructions on what to expect at test were given. The JOL

questions were the same with those used in Experiment 1.

Results

In Experiment 4, we analyzed recognition hits and FAs separately for younger

and older adults. The design for analyses matched Experiment 1, except that here

a 2-level between-subject factor "Order (Associated first, Unassociated first)" was

added.

Younger adults Hits. A repeated measures ANOVA on younger adults' hit

rates yielded a main effect of Spatial Organization [$F(1, 28) = 10.12$, $p = .004$, ηp^2

= .27]. Spatial organization improved younger adults' recognition performance in

general (Means: Organized = .82, Unorganized = .76). This main effect, however,

was qualified by the interaction between Spatial Organization and Question Type,

$F(2, 27) = 4.44$, $p = .022$, $\eta p^2 = .25$. Spatial Organization improved participants'

performance, but only on location trials (Means: Organized = .89, Unorganized

= .75; $t(29) = 3.80$, $p < .001$, $d = .83$). Spatial organization did not benefit younger

adults on their object memory (Means: Organized = .82, Unorganized = .77) or

combination memory (Means: Organized = .76, Unorganized = .76).

Younger adults False Alarms. Analyses on location trials yielded main

effects of Spatial Organization and Semantic Association [$F(1,28) = 31.67$, p

$<.001$, $\eta p^2 = .53$; $F(1,28) = 15.30$, $p = .001$, $\eta p^2 = .35$]. Both spatial organization

and semantic association reduced young participants' location FAs. Specifically,

younger adults made more false alarms when the grids were unorganized ($M = .24$)

than organized ($M = .06$); they also false-alarmed more when the studied objects

were unassociated ($M = .18$) as compared with associated ($M = .11$). A significant

interaction between Semantic Association and Order was observed, $F(1,28) =$

8.84, $p = .006$, $\eta p^2 = .24$. The associated-first group outperformed

unassociated-first group on unassociated grids, with a better performance (lower

FA rate) on location trials. The associated-first group performed equally well on

the associated ($M = .11$) and unassociated blocks ($M = .12$), where as the

unassociated-first group made more FAs with the unassociated block (Means:

Unassociated = .24, Associated = .13; $t(14) = 2.51$, $p = .03$, $d = .95$).

FAs analysis on object trials yielded a main effect of Lure Type, $F(1, 28) =$

36.66, $p < .001$, $\eta p^2 = .57$. Younger adults made more false alarms to related (M

= .19) than to unrelated lures ($M = .06$). We also found an interaction between

Semantic Association and Lure Type, $F(1, 28) = 17.21$, p $< .001$, $\eta p^2 = .38$. Lure

types affected participants' FAs, but only when the studied objects were

associated semantically (Means: Related lure = .23, Unrelated lure = .02; $t(29) =$

7.78, $p < .001$, $d = 1.75$). If grids had been unassociated, no difference was found

in FAs across different lure types (Means: Related lure = .14, Unrelated lure

= .09). In addition, Semantic Association and Spatial Organization interacted, $F(1,$

28) = 8.6, p = .007, $\eta p^2 = .24$. When the grids were associated, spatial

organization increased younger adults' object FAs (Means: Organized = .17,

Unorganized = .08; $t(29) = 2.14$, $p = .04$, $d = .58$); however, when grids were

unassociated, participants false-alarmed more with unorganized grids (Means:

Unorganized = .15, Organized = .08; $t(29) = 2.16$, $p = .04$, $d = .40$).

On combination trials, repeated measures ANOVA revealed main effects of

Semantic Association [$F(1,28) = 8.91$, $p = .006$, $\eta p^2 = .24$], and Lure Type [$F(4,$

25) = 11.50, $p < .001$, $\eta p^2 = .65$]. Semantic association benefited younger adults'

memory for object-location binding by reducing FAs (Means: Unassociated = .08,

Associated = .12). Lure type also affected memory. Participants made more FAs

when lures were the same or related to studied objects (Means: New location Old

object = .20, Old location Related object = .16; see Table 8 for all means).

We also found an interaction between Spatial Organization and Lure Type on

combination trials [$F(4,25) = 3.17$, $p = .031$, $\eta p^2 = .34$]. Spatial organization only

reduced younger adults' FAs to old-location-unrelated-object lures (Means:

Unorganized = .12, Organized = .02; $t(29) = 1.98$, $p = .05$, $d = .45$). No

differences were found across other lure types (see Figure 9). Meanwhile, an

interaction between Semantic Association and Lure Type was found [$F(4,25) =$

3.60, $p = .02$, $\eta p^2 = .37$]. As demonstrated in Figure 10, younger participants had

more FAs to new-location-old-object lures (Means: Unassociated = .24,

Associated = .16; $t(29) = 2.01$, $p = .05$, $d = .57$), and new-location-related-object

lures (Means: Unassociated = .11, Associated = .03; $t(29) = 2.19$, $p = .04$, $d = .59$),

when grids were semantically unassociated.

Older Adults Hits. A repeated measures ANOVA yielded main effects of

Spatial Organization, Semantic Association, and Question type [$F(1, 30) = 15.22$,

$p = .001$, $\eta p^2 = .34$; $F(1, 30) = 12.51$, $p = .001$, $\eta p^2 = .29$; $F(2, 29) = 6.65$, $p = .004$,

$\eta p^2 = .31$]. Overall, spatial organization and semantic association improved hit

rates. Older adults performed better when the grids were organized ($M = .73$) than

unorganized ($M = .61$); they were also more accurate when the grids were

associated ($M = .71$) as opposed to unassociated ($M = .63$). In this experiment,

older adults also demonstrated different performances on different types of

questions, showing greater accuracy with object ($M = .75$) than either location (M

$= .64$) or combination memory ($M = .62$). We also found a significant interaction

between Spatial Organization and Question Type [$F(2, 29) = 6.27$, $p = .005$, ηp^2

$= .30$]. Spatial Organization facilitated older adults' location memory (Means:

Organized $= .77$, Unorganized $= .52$; $t(31) = 5.25$, $p < .001$, $d = .89$), but not their

object (Means: Organized $= .76$, Unorganized $= .73$) or combination memory

(Means: Organized $= .65$, Unorganized $= .59$). In addition, the interaction between

Semantic Association and Order was marginally significant, $F(1, 30) = 4.47$, p

$= .07$, $\eta p^2 = .10$. The unassociated-first group ($M = .68$) outperformed the

associated-first group ($M = .57$) only on the unassociated grids, suggesting an

effect of order on older adults' VSWM processing.

Older Adults False Alarms. On location trials, a main effect of Spatial

Organization was found [$F(1,30) = 11.17$, $p = .002$, $\eta p^2 = .27$]. Spatial

organization helped older adults by reducing location FAs (Means: Unorganized

$= .17$, Organized $= .07$).

Repeated measures ANOVA on object FAs yielded main effects of Lure

Type, and Order [$F(1, 30) = 19.65$, $p < .001$, $\eta p^2 = .40$; $F(1, 30) = 6.10$, $p = .02$,

$\eta p^2 = .17$]. Similar to Experiment 1, older adults false-alarmed more to related (M

= .19) as compared with unrelated lures (M = .06). In addition, block order

mattered. Participants who completed the unassociated block first demonstrated

higher FA rates on object memory (M = .17), as compared with those who did the

associated block first (M = .08). We also found a significant interaction between

Semantic Association and Order, $F(1, 30)$ = 5.14, p = .031, ηp^2 = .15. Block order

did not affect false alarms with associated grids (Means: Associated first = .11,

Unassociated first = .15); however, with unassociated grids, the unassociated-first

group (M = .19) made more FAs than the associated-first group (M = .05). This

finding suggests an effect of order on older adults' object memory.

For combination trials, the only effect we found was the main effect of Lure

Type, $F(4, 27)$ = 10.24, $p < .001$, ηp^2 = .60. More specifically, older adults false

alarmed more when lures were the same or related to studied objects (Means:

New location Old object = .14, Old location Related object = .12; for all means

see Table 8). When emphasizing object processing through blocking, older adults

were less efficient in using spatial or semantic relationships for lure-rejection in

combination trials.

Discussion

Experiment 4 examined whether making object information more salient

would affect VSWM. We hypothesized that accentuating semantic relatedness

through blocking would reduce the resource demands for object processing. This

would in turn facilitate object memory for older adults, as they might need extra environmental support at encoding. However, making object information more salient could also benefit younger adults, as they seem to benefit less on object processing than on location processing in VSWM.

We found that for younger adults, blocking trials by semantic relationships reduced the facilitative effect of semantic association on their object memory. However, the effect was reduced because blocking slightly improved younger adults' performance on the unassociated trials, as compared with Experiment 1. Blocking by semantic association improved their memory accuracy on unassociated grids ($M = .77$), as compared with Experiment 1 ($M = .70$), suggesting that younger adults might have benefited from the accentuated semantic relationships.

For older adults, blocking trials by semantic associations did not reduce the effect of semantic association on object memory when compared to Experiment 1. However, we found that encouraging semantic processing improved older adults' VSWM overall. Specifically, when the unassociated block was presented first, older adults performed as well on unassociated as associate trials (collapsed across question); when the associated block was presented first, performance was worse on the unassociated grids than associated (collapsed across question). This block order affected only older adults but not younger adults, unlike Experiment 3.

Considering previous findings that older adults tend to rely on semantic

information (Thomas, & Sommers, 2005), it is possible that with the unassociated

block came first, older adults might have strategically imposed some semantic

relationships from the unassociated objects to help their VSWM. Experiment 4

findings suggest that although older adults might not be as efficient as younger

adults in using spatial relationships to help memory, they could be, at some level,

more efficient than their younger counterparts in using semantic-related strategies

to facilitate VSWM processing.

General Discussion

The present study sought to explore how individual VSWM attributes are

processed and interacted, and whether factors that influence only object or spatial

processing also affect their binding in VSWM. Towards this end, we

systematically manipulated spatial organization, semantic association, and

strategic processing in four experiments, examining both younger and older adults.

Although many studies have explored how spatial organization, semantic

association and strategic processing affect long-term spatial memory (Hirtle, &

Mascolo, 1986; Merrill, & Baird, 1987; Maddox, Rapp, Brion, & Taylor, 2008),

only a few studies have looked at how these factors affect VSWM. The present

study is among the first to explore these factors with both younger and older

adults using a VSWM paradigm. Results showed that these factors influence the

processing and interaction of VSWM attributes differently based on age. Our

findings also support the idea that location may not be automatically encoded in

VSWM. We found that location encoding can be improved by spatial organization

and strategic processing, suggesting that location encoding may not meet the

criteria for automatic process proposed by Hasher and Zacks (1979).

In this section, we discuss our findings and two possible accounts to both

better understand the results and provide insights into future directions.

Effect of Spatial Organization and Semantic Association on Younger and

Older Adults' VSWM Processing

The present work extended our previous work by examining how spatial

organization affects younger and older adults' VSWM. Across all experiments,

spatial organization benefited both younger and older participants. The nature of

the benefit differed by age. For younger adults, consistent with our previous

finding (Taylor, Thomas, Artuso, & Eastman, 2014), spatial organization only

helped location memory. For older adults, similar to their younger counterparts,

spatial organization benefited location memory across all experiments; however,

spatial organizations also facilitated older adults' object memory (Experiment 1),

and combination memory, when spatial organization was emphasized (Experiment

3). This indicates that older adults can use spatial relationships when processing

visuo-spatial information. Additionally, the facilitative effect of spatial

organization on younger and older adults' location memory suggested that

location encoding failed to meet the criteria of automaticity, supporting the idea

that location information is not automatically encoded in VSWM.

Semantic association also affected younger and older adults differently. For

younger adults, semantic association improved their object memory, except when

semantic relationships were emphasized on (in Experiment 4). For older adults,

while consistently increased correct responses for object identities, semantic

association also impaired their VSWM by increasing false alarms to lures. It is

possible that the increase in both hits and false alarms may suggest a criterion

shift in older adults' responses. However, it is also possible that, consistent with

our prediction, older adults may be overly relying on semantic processing in

VSWM that they are biased by semantic association.

Effect of Strategic Processing on Younger and Older Adults' VSWM

Processing

In general, we found that strategic processing affected both younger and older

adults, but in different ways. For instance, we hypothesized that blocking by

question types (Experiment 2) would encourage a focus on information relevant

to specific question, thereby improving memory for individual VSWM attributes.

Partly consistent with this prediction, we found that blocking by question type

benefited both younger and older adults, but on different VSWM components.

When strategically processing only question relevant information, younger adults

showed improved location memory and reduced combination false alarms,

whereas older adults only showed reduced false alarms on combination memory.

In other words, comparing with younger adults, older adults might have benefited

less from strategically focusing on individual VSWM attribute. This suggests

possible deficits of older adults in either consciously using strategic processing, or

focusing resources on targeted processing while simultaneously suppressing

irrelevant information.

In addition, we found that participants only improved processing the

attributes they tended to rely on. Specifically, indirectly encouraging location

processing facilitated younger adults, whereas encouraging object processing

facilitated older adults. This finding contradicts our predictions, and further

suggests that even on the attribute where certain group of participants shows an

advantage, they could still improve if that attribute is emphasized.

One possible explanation for this finding is that participants might have

imposed spatial or semantic relationships to help with their VSWM. For instance,

indirectly encouraging location processing might facilitate younger adults' ability

to impose spatial relationships on unorganized objects. Thomas et al. (2012)

suggested that participants might have generated spatial relationships to help their

location memory, resulting in stable location memory accuracy when the array

size was large enough to generate a spatial organization. In the present study,

younger adults performed better on unorganized trials if they finished these trials

first (Experiment 3). It is possible that showing younger adults spatial

organizations first may have facilitated their ability to impose spatial

organizations, when no such relationships were available.

Similarly, indirectly encouraging object processing might have helped older

adults in generating semantic relationships among unassociated objects.

Specifically, older adults performed better on unassociated trials when they

completed the unassociated block first. One possible explanation for this finding

could be that older adults tend to rely on semantic relationships. When no such

relationships were available to rely on, they could either strategically impose

semantic associations, or engage in item-specific processing and encode

individual items.

While it is possible that younger and older adults tried to impose some

relationships from the objects to help with their VSWM, it remains unclear

whether they were consciously engaged in using such strategies. To address this

possibility, future studies could provide participants with explicit instructions on

possible strategic processing.

Effect of Aging on VSWM Processing

Based on previous findings that aging influences VSWM processing

(Thomas, Bonura, Taylor, & Brunyé, 2012), and that older adults cognitively

process more slowly than younger adults (Hale, Myerson, & Wagstaff, 1987;

Salthouse, 1979), in this study, we "evened the playing field" by giving older

adults more time to process grids. This manipulation minimized generalized

slowing effects for older adults' VSWM. Considering this difference in

presentation time, we did not directly compare the two age groups.

We found across all experiments that influential factors, such as spatial

organization, semantic association and strategic processing, differentially affected

younger and older adults VSWM processing. Specifically, our findings indicate

that younger adults were more likely to rely on spatial organization than semantic

association; older adults, however, tended to rely more on semantic as compared

to location processing. In addition, when indirectly encouraging strategy use,

older adults demonstrated limited benefit from strategic processing, suggesting

that indirect support may not be sufficient for them to engage in strategic

processing effectively. More explicit support may be needed according to the

environmental support (ES) hypothesis (Craik, 1983). One main argument of the

ES hypothesis is that age-related deficits could be reduced if the task environment

provides older adults with task-appropriate cues. Thus to facilitate strategic

processing, older adults may need more explicit instructions, depending on the

type of task involved. This is also consistent with previous literature that older

adults may need explicit instructions to encode and use spatial and semantic

information in map studies (Thomas, Bonura, Taylor, & Brunyé, 2012). In

addition, from a more practical perspective, our finding that older adults may need

distinctive external cues with spatial memory adds to evidence that, when making

regulations and modifications, policy makers should take age-related changes into

consideration, and facilitate the outsourcing of memory for older adults by

providing more environmental support (Ross, & Schryer, 2015).

To further understand the different patterns in younger and older adults found

in the present study, here we consider two possible accounts, the *resource*

reduction framework and the *race model* framework.

The *resource reduction* framework stems from the asymmetry in cognitive

resource demands for different VSWM attributes. As explained in the introduction,

object processing and location processing, with different resource requirements,

compete with each other for cognitive resources. Many factors could affect

attribute processing, possibly by shifting around the resource demands associated

with a specific attribute processing. Changes in cognitive resource demands affect

ease in processing, which may in turn result in better or worse memory for that

attribute. For example, spatial organization improved location memory, possibly

by reducing the cognitive resources needed for location encoding, which in turn

increased ease in processing location information. Spatial organization also

facilitated older adults' object and combination memory. It is possible that spatial

organization brings in resource reduction for older adults in location processing,

so they could allocate more resources on object processing and object-location

binding. Similarly, semantic association and strategic processing might have

shifted around the cognitive demands of different VSWM components, affecting

younger and older participants' memory for different attributes. However, while

our results did not provide direct evidence for this idea, future research can

address this possibility by examining cognitive recourse demands in VSWM

attribute processing.

The *race model* framework can also help us understand the process and

binding of VSWM attributes. According to the *race models*, items or attributes in

the display compete to be processed. However, only the items that get to the final

state will "win" the race (Bundesen, 1987; Bundesen, 1990). Based on this

account, in VSWM, when spatial location information and object identity

information are both in the display, they may compete to get to the final

"processed" state. The attribute that receives more processing when presentation

time ends will "win" and have stronger memory representation. As discussed

earlier, multiple factors may influence this race process. Spatial organization,

semantic association, and strategic processing may all affect younger and older

adults' VSWM by differentially affecting relative weightings of location and

object processing in the race. What we found in the present study fits well with

this account. For instance, spatial organization improved location memory,

possibly weighting location information more and "speeding up" location

encoding. Semantic association, as another example, facilitated object memory or

object-location binding for younger and older adults, respectively, possibly by

speeding up object processing or facilitating object-location binding. Strategic

processing also affected VSWM in different age groups, potentially by changing

the weightings of attributes. However, we should note that the present study did

not directly test this framework; what remained unclear, is whether, and if "yes",

how do these factors affect the "race" differently in younger and older adults.

Differential weightings of VSWM attributes by younger and older adults may

provide an explanation. Future studies can examine this possibility.

Other factors might have contributed to the aging effect on VSWM found in

the present study. For instance, participants made judgments of learning (JOLs)

between studying each grid and test. We included these JOL questions to examine

younger and older adults' metacognition, but because this thesis focuses mainly

on VSWM, JOL data are not presented here. Nonetheless, including these JOL

questions might have impacted the results. Answering a JOL question introduces a

delay between study and test, allowing for interference or decay of studied

information. Also, cognitive demands of making a JOL for older adults, might

increase the overall cognitive burden and in turn negatively affect retrieval.

Additionally, with a young experimenter, older adults might have experienced

stereotype threat, which could also negatively impact memory performance. Thus

making JOLs between the study phase and test phase might have affected memory

performance, especially for older adults.

Conclusion

The present study sought to further explore how VSWM attributes are

processed both separately and together, and whether factors that influence only

object or spatial processing also affect their binding in VSWM tasks. We

systematically manipulated spatial organization, semantic association, and

strategic processing in a VSWM paradigm, testing both younger and older adults.

We found that younger and older adults were differentially affected by these

factors, demonstrating different patterns when processing visuo-spatial

information, even when older adults had more study time to achieve equivalent

encoding with their younger counterparts.

Although many studies had explored the individual effect of spatial

organization, semantic association and strategic processing on long-term spatial

memory, the present study is among the first to explore the effect of these factors,

and their interactions, on younger and older adults' VSWM. Our finding

supported the idea that location may not be automatically encoded, shedding light

on the debate over the automaticity of location encoding. More importantly, the

present research contributes to the lacking literature on how younger and older

adults differentially engage in strategic processing in VSWM, providing useful

guidance for experimenters to design future studies for younger and older adults.

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Appendix A

18 Semantic Categories and names of the items

Categories	Names of the items
Furniture	Chair
	Dresser
	Desk
	Table
	Stool
	Bed
	Couch
	Love seat
	Folding table
	Rocking chair
Transportation	Car
	Plane
	Train
	Motorcycle
	Boat
	Bus
	Sledge
	Bicycle
	Truck
	Helicopter
Body Parts	Lips
	Foot
	Hand
	Nose
	Eye
	Ear
	Hair
	Finger
	Arm
	Leg
Instruments	Flute
	Trumpet

Drum

Harp

Piano

Guitar

Drum set

Violin

Accordion

Saxophone

Clothing/Accessories

Hat

Tie

Belt

Glasses

Watch

Glove

Purse

Necklace

Casquette

Bowknot

Clothing

Sock

Shirt

Skirt

Pants

Dress

Vest

Coat

Boots

Blouse

Sweater

Fruit

Strawberry

Pineapple

Orange

Grapes

Cherry

Banana

Watermelon

Pear

Lemon
Apple

Birds

Owl
Rooster
Swan
Eagle
Penguin
Peacock
Duck
Hen
Nightingale
Ostrich

Zoo Animals

Gorilla
Elephant
Camel
Tiger
Zebra
Giraffe
Deer
Monkey
Rhinoceros
Lion

Tools

Axe
Pliers
Screwdriver
Wrench
Saw
Hammer
Screw cap
Nail
Screw
File

Vegetables

Corn
Carrot
Celery

Mushroom
Pepper
Tomato
Potato
Onion
Lettuce
Pumpkin

Sports Equipment   Football
Helmet
Bat
Whistle
Racquet
Niblick
Dartboard
Basketball
Baseball glove
Soccer ball

Toys   Ball
Roller Skate
Kite
Swing
Top
Doll
Rocking horse
Lego Man
Balloon
Rubik cube

Kitchen Items   Rolling Pin
Pan
Kettle
Fork
Bowl
Glass
Wineglass
Spoon
Saltshaker

Fry pan

Office Supplies   Envelope

Pen

Pencil

Ruler

Scissors

Paper clip

Folder

Eraser

Calculator

Stapler

Household appliances   Toaster

Television

Telephone

Stove

Refrigerator

Record player

Bulb

Lamp

Iron

Fan

Insects   Spider

Grasshopper

Fly

Carpenter-worm

Butterfly

Dung beetle

Ant

Bee

Mantis

Mosquito

Aquatic animals   Whale

Shark

Octopus

Jelly fish

Golden fish

Crab

Turtle

Sea horse

Lobster

Fish

Appendix B

VOCABULARY TEST

Participant #_____ Date: _____ Age_____ Sex: _____

Highest level of school completed (circle one): middle school   some high school
     high school   some college   college   advanced degree

In each word in capital letters, underline the word in the group below it that has the same meaning. The first one with CONNECT is an example.

1. CONNECT
accident	<u>join</u>
lace	bean
flirt	pierce

2. PROVIDE
harmonize	commit
hurt	supply
annoy	divide

3. STUBBORN
obstinate	steady
hopeful	hollow
orderly	slack

4. SCHOONER
building	man
ship	singer
plant	scholar

5. LIBERTY
worry	freedom
rich	serviette
forest	cheerful

6. COURTEOUS
dreadful	proud
truthful	short
curtsey	polite

7. RESEMBLANCE
attendance	fondness
assemble	repose
likeness	memory

8. THRIVE
flourish	cry
thrash	leap
field	think

9. PRECISE
natural	stupid
faulty	grand
small	exact

10. ELEVATE
revolve	move
raise	work
waver	disperse

11. LAVISH
unaccountable	selfish
romantic	lawful
extravagant	praise

12. SURMOUNT
mountain	descend
overcome	concede
appease	snub

13. BOMBASTIC
democratic	pompous
bickering	cautious
destructive	anxious

14. ENVISAGE
contemplate	activate
surround	estrange
enfeeble	regress

15. PERPETUATE
appropriate	commit
propitiate	deface
blame	control

16. LIBERTINE
missionary	rescuer
profligate	canard
regicide	farrago

17. QUERULOUS
astringent	fearful
petulant	curious
inquiring	spurious

18. FECUND
esculent	optative
profound	prolific
sublime	salic

19. ABNEGATE
contradict	decry
renounce	execute
belie	assemble

20. TRADUCE
challenge	attenuate
suspend	establish
misrepresent	conclude

21. TEMERITY
impermanence	rashness
nervousness	stability
punctuality	submissiveness

Table 1.

*Experiment 1 – Younger and Older Adults' Mean Proportion of Hits of each
Question Type, by Grid Conditions. Standard deviation is in parentheses.*

Age Group	Question Type	Grid Conditions			
		Organized Associated	Organized Unassociated	Unorganized Associated	Unorganized Unassociated
YAs					
	Location	.87 (.22)	.79 (.25)	.51 (.38)	.54 (.36)
	Object	.83 (.29)	.69 (.38)	.82 (.29)	.69 (.36)
	Combination	.70 (.23)	.66 (.27)	.67 (.20)	.69 (.30)
OAs					
	Location	.78 (.32)	.75 (.32)	.49 (.34)	.47 (.43)
	Object	.84 (.31)	.73 (.32)	.67 (.35)	.57 (.38)
	Combination	.69 (.23)	.62 (.30)	.64 (.26)	.54 (.25)

Note. YAs = Younger adults; OAs = Older adults.

Table 2.

Experiment 1 – Younger and Older Adults' Mean False Alarms to different Lure Types by Question Type. Standard deviation is in parentheses.

Question Type	Lure Type	Age Group	
		YAs	OAs
Location			
	Location Lures	.16 (*.13*)	.14 (*.13*)
Object			
	Related Lures	.18 (*.15*)	.22 (*.16*)
	Unrelated Lures	.07 (*.10*)	.06 (*.08*)
Combination			
	New Location Old Object Lures	.22 (*.17*)	.19 (*.17*)
	New Location Related Object Lures	.08 (*.11*)	.06 (*.07*)
	New Location Unrelated Object Lures	.03 (*.05*)	.01 (*.03*)
	Old Location Related Object Lures	.14 (*.14*)	.12 (*.12*)
	Old Location Unrelated Object Lures	.05 (*.06*)	.05 (*.07*)

Note. YAs = Younger adults; OAs = Older adults.

Table 3.

Experiment 2 – Younger and Older Adults' Mean Proportion of Hits of each Question Type, by Grid Conditions. Standard deviation is in parentheses.

Age Group	Question Type	Grid Conditions			
		Organized Associated	Organized Unassociated	Unorganized Associated	Unorganized Unassociated
YAs					
	Location	.94 (*.16*)	.84 (*.27*)	.69 (*.37*)	.71 (*.29*)
	Object	.88 (*.25*)	.69 (*.37*)	.86 (*.22*)	.80 (*.28*)
	Combination	.70 (*.25*)	.64 (*.21*)	.65 (*.27*)	.60 (*.21*)
OAs					
	Location	.82 (*.35*)	.70 (*.38*)	.48 (*.44*)	.46 (*.32*)
	Object	.78 (*.32*)	.66 (*.31*)	.70 (*.35*)	.64 (*.36*)
	Combination	.77 (*.15*)	.58 (*.23*)	.70 (*.21*)	.64 (*.32*)

*Note.* YAs = Younger adults; OAs = Older adults.

Table 4.

Experiment 2 – Younger and Older Adults' mean False Alarms to different Lure Types by Question Type. Standard deviation is in parentheses.

Question Type	Lure Type	Age Group	
		YAs	OAs
Location			
	Location Lures	.10 (*.07*)	.08 (*.08*)
Object			
	Related Lures	.10 (*.10*)	.06 (*.06*)
	Unrelated Lures	.05 (*.09*)	.04 (*.06*)
Combination			
	New Location Old Object Lures	.18 (*.11*)	.18 (*.14*)
	New Location Related Object Lures	.08 (*.08*)	.05 (*.06*)
	New Location Unrelated Object Lures	.03 (*.06*)	.01 (*.03*)
	Old Location Related Object Lures	.14 (*.11*)	.14 (*.14*)
	Old Location Unrelated Object Lures	.05 (*.08*)	.03 (*.06*)

Note. YAs = Younger adults; OAs = Older adults.

Table 5.

Experiment 3 – Younger and Older Adults' Mean Proportion of Hits of each Question Type, by Grid Conditions. Standard deviation is in parentheses.

Age Group	Question Type	Grid Conditions			
		Organized Associated	Organized Unassociated	Unorganized Associated	Unorganized Unassociated
YAs					
	Location	.78 (*.31*)	.72 (*.35*)	.69 (*.30*)	.63 (*.35*)
	Object	.81 (*.28*)	.68 (*.32*)	.76 (*.33*)	.59 (*.34*)
	Combination	.66 (*.20*)	.64 (*.22*)	.71 (*.24*)	.66 (*.22*)
OAs					
	Location	.72 (*.39*)	.72 (*.41*)	.42 (*.42*)	.53 (*.45*)
	Object	.85 (*.23*)	.60 (*.36*)	.77 (*.29*)	.73 (*.37*)
	Combination	.74 (*.22*)	.56 (*.23*)	.69 (*.28*)	.61 (*.29*)

Note. YAs = Younger adults; OAs = Older adult.

Table 6.

Experiment 3 – Younger and Older Adults' Mean False Alarms to different Lure Types by Question Type. Standard deviation is in parentheses.

Question Type	Lure Type	Age Group	
		YAs	OAs
Location			
	Location Lures	.19 (*.10*)	.13 (*.16*)
Object			
	Related Lures	.15 (*.11*)	.18 (*.16*)
	Unrelated Lures	.06 (*.09*)	.06 (*.10*)
Combination			
	New Location Old Object Lures	.19 (*.17*)	.26 (*.25*)
	New Location Related Object Lures	.09 (*.10*)	.08 (*.13*)
	New Location Unrelated Object Lures	.02 (*.04*)	.01 (*.02*)
	Old Location Related Object Lures	.14 (*.12*)	.15 (*.14*)
	Old Location Unrelated Object Lures	.02 (*.05*)	.03 (*.05*)

Note. YAs = Younger adults; OAs = Older adults.

Table 7.

Experiment 4 – Younger and Older Adults' Mean Proportion of Hits of each
Question Type, by Grid Conditions. Standard deviation is in parentheses.

Age Group	Question Type	Grid Conditions			
		Organized Associated	Organized Unassociated	Unorganized Associated	Unorganized Unassociated
YAs					
	Location	.90 (*.20*)	.88 (*.22*)	.73 (*.31*)	.77 (*.29*)
	Object	.85 (*.27*)	.78 (*.31*)	.78 (*.34*)	.75 (*.29*)
	Combination	.75 (*.22*)	.77 (*.23*)	.73 (*.23*)	.79 (*.19*)
OAs					
	Location	.80 (*.28*)	.73 (*.40*)	.53 (*.38*)	.50 (*.34*)
	Object	.81 (*.28*)	.70 (*.31*)	.84 (*.30*)	.63 (*.42*)
	Combination	.71 (*.24*)	.60 (*.26*)	.59 (*.25*)	.59 (*.24*)

Note. YAs = Younger adults; OAs = Older adults.

Table 8.

Experiment 4 – Younger and Older Adults' Mean False Alarms to different Lure Types by Question Type. Standard deviation is in parentheses.

Question Type	Lure Type	Age Group	
		YAs	OAs
Location			
	Location Lures	.15 (*.10*)	.12 (*.10*)
Object			
	Related Lures	.19 (*.13*)	.19 (*.17*)
	Unrelated Lures	.06 (*.09*)	.05 (*.09*)
Combination			
	New Location Old Object Lures	.20 (*.17*)	.14 (*.13*)
	New Location Related Object Lures	.07 (*.09*)	.05 (*.08*)
	New Location Unrelated Object Lures	.03 (*.05*)	.02 (*.05*)
	Old Location Related Object Lures	.16 (*.19*)	.12 (*.15*)
	Old Location Unrelated Object Lures	.07 (.09)	.04 (*.08*)

Note. YAs = Younger adults; OAs = Older adults.

a. Sample objects
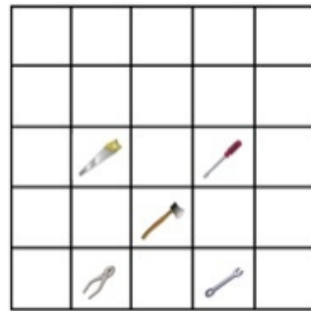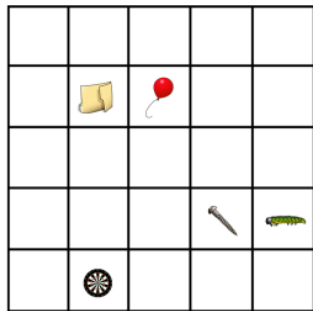
b. Sample unorganized & unrelated grid.   c. Sample organized & related grid.
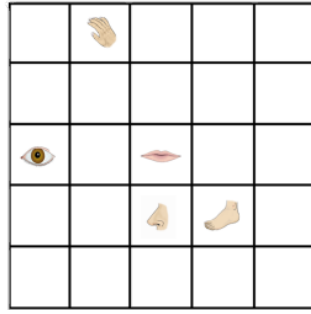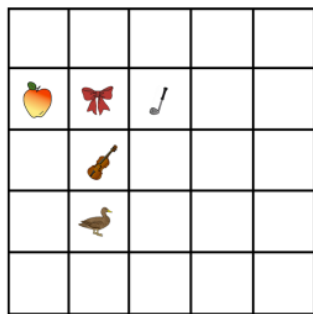
d. Sample organized & unrelated grid.   e. Sample unorganized & unrelated grid.

Figure 1.
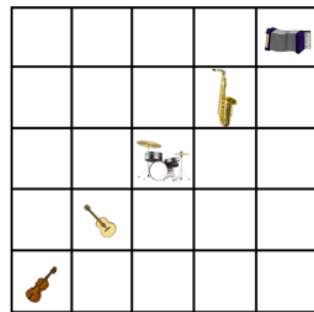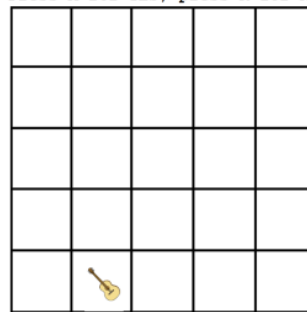
a. New location and old object
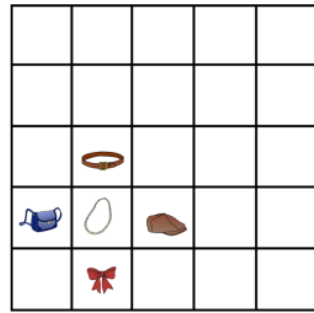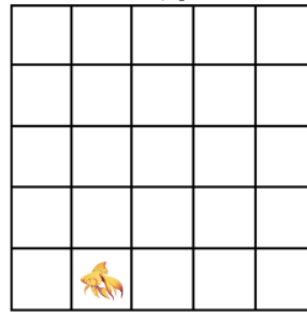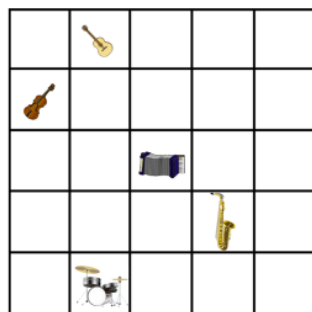
b. Old location and unrelated object

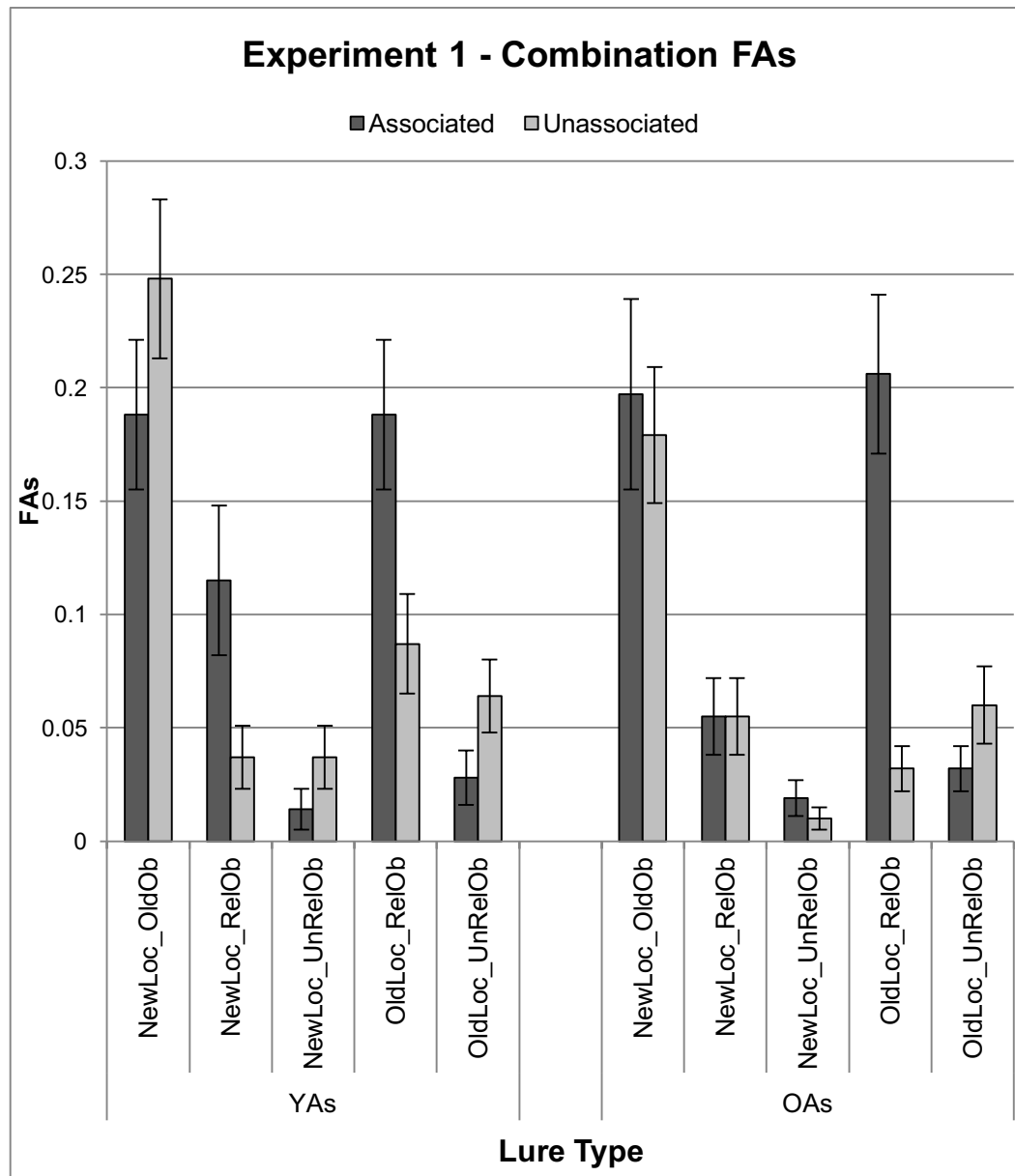c. Old location and related object
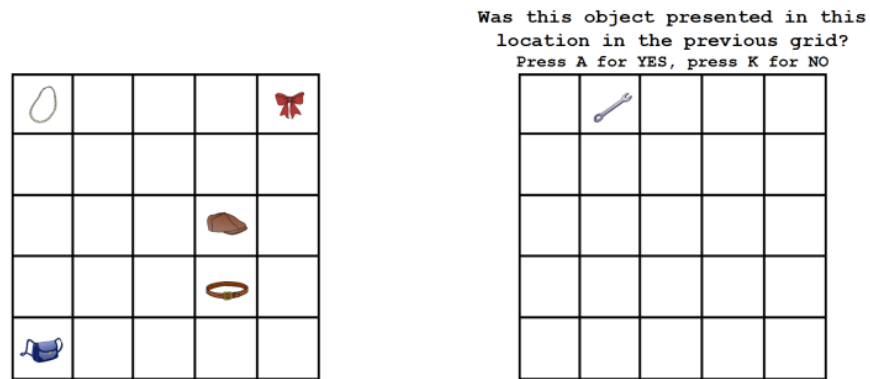
d. New location and unrelated object
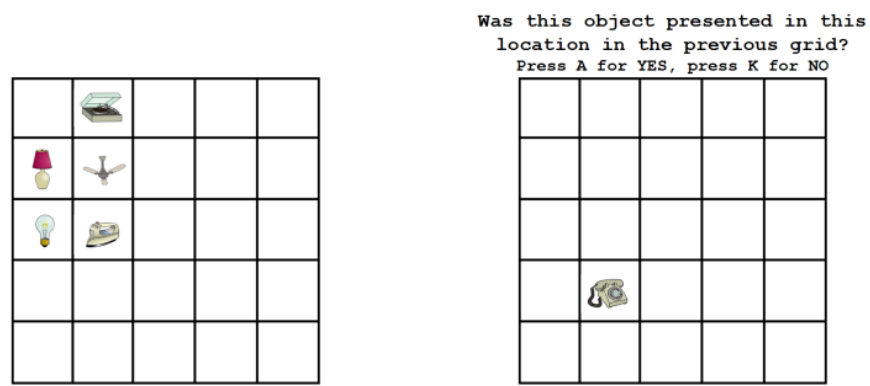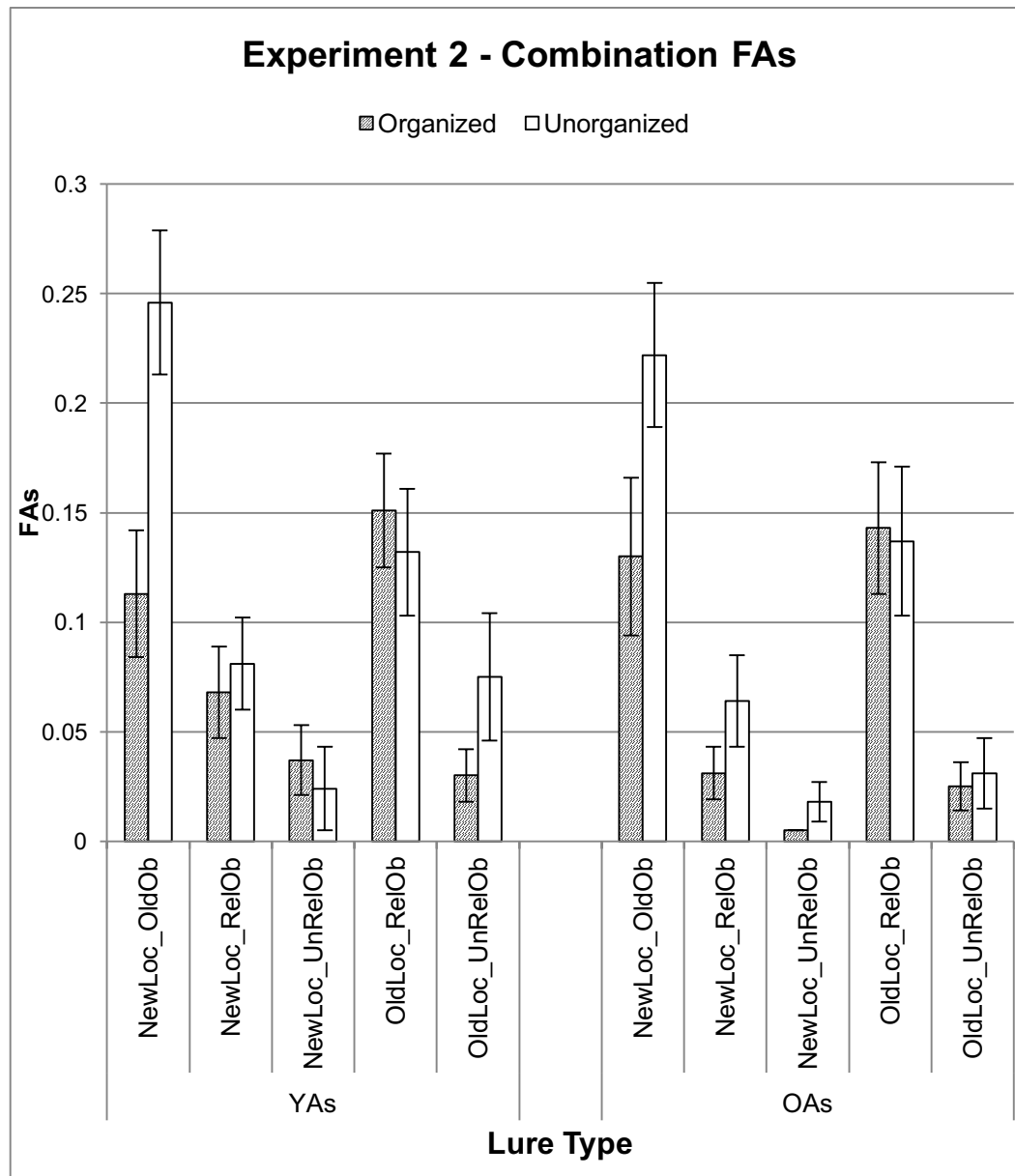

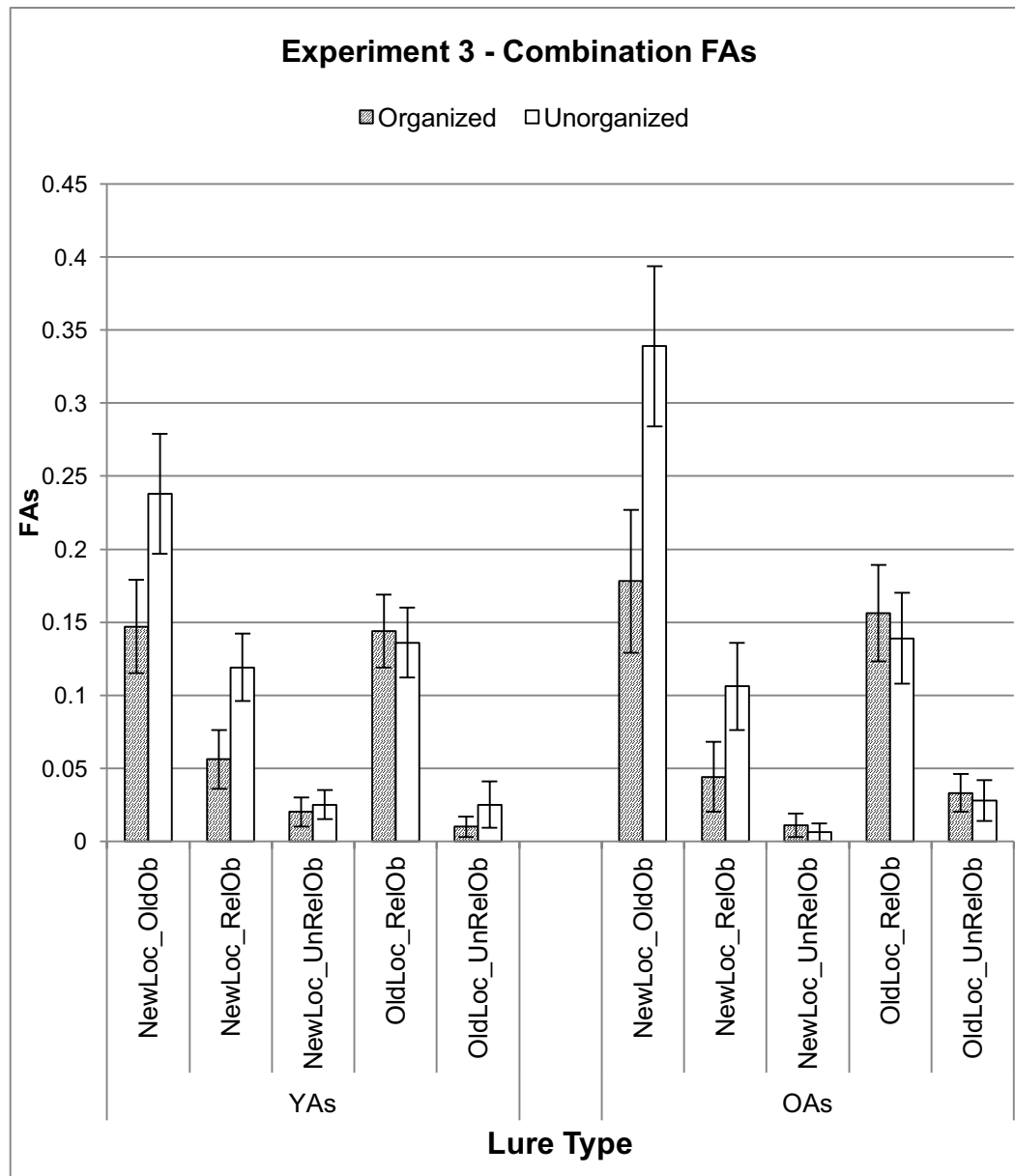e. New location and related object

Figure 2.
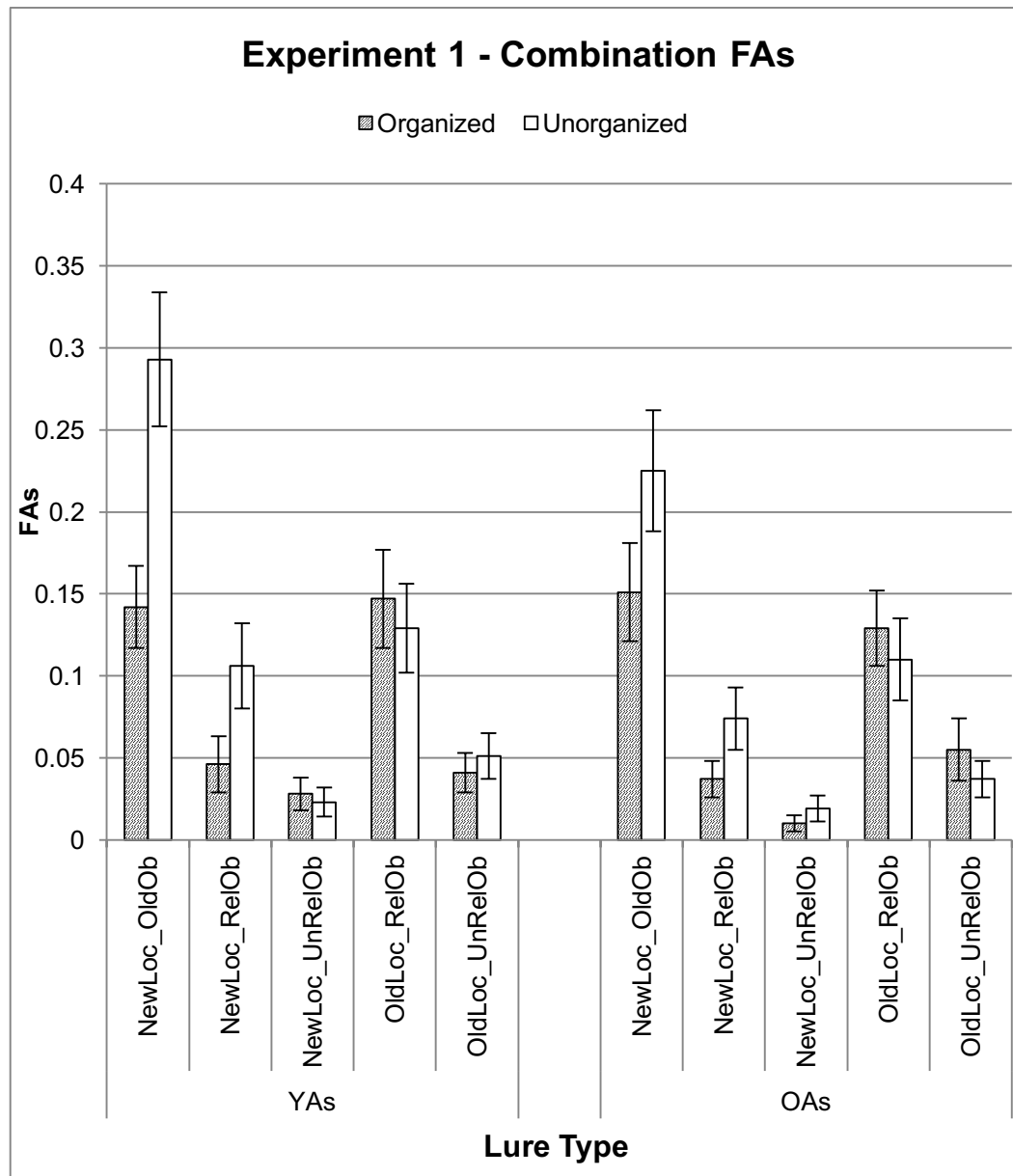
Note. YAs = Younger adults; OAs = Older adults; NewLoc_OldOb = New location old object lure; NewLoc_RelOb = New location related object lure; NewLoc_UnRelOb = New location unrelated object lure; OldLoc_RelOb = Old location related object lure; OldLoc_UnRelOb = Old location unrelated object lure.

Figure 3.

Note. YAs = Younger adults; OAs = Older adults; NewLoc_OldOb = New location old object lure; NewLoc_RelOb = New location related object lure; NewLoc_UnRelOb = New location unrelated object lure; OldLoc_RelOb = Old location related object lure; OldLoc_UnRelOb = Old location unrelated object lure.
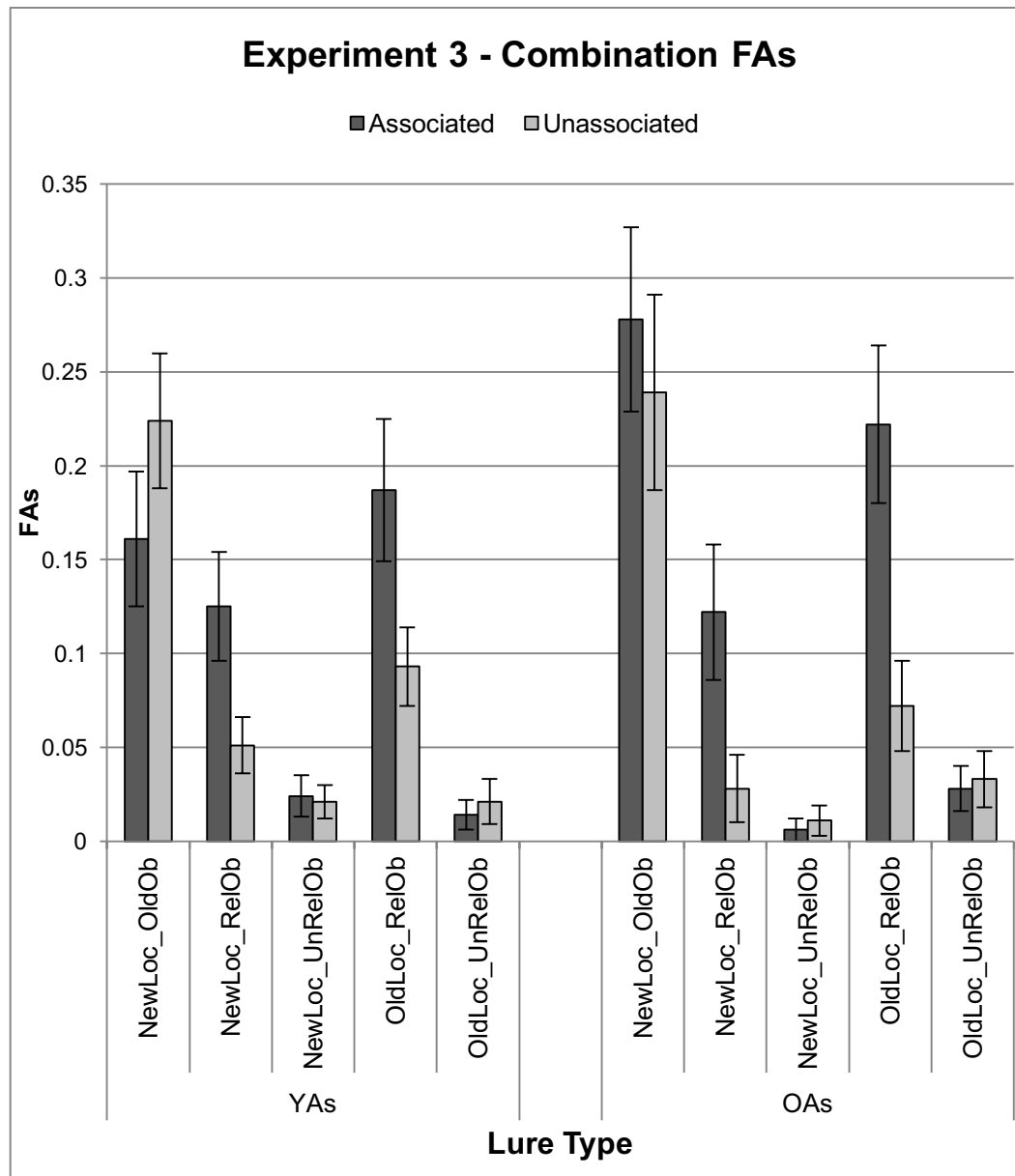
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Note. YAs = Younger adults; OAs = Older adults; NewLoc_OldOb = New location old object lure; NewLoc_RelOb = New location related object lure; NewLoc_UnRelOb = New location unrelated object lure; OldLoc_RelOb = Old location related object lure; OldLoc_UnRelOb = Old location unrelated object lure.

Figure 5.
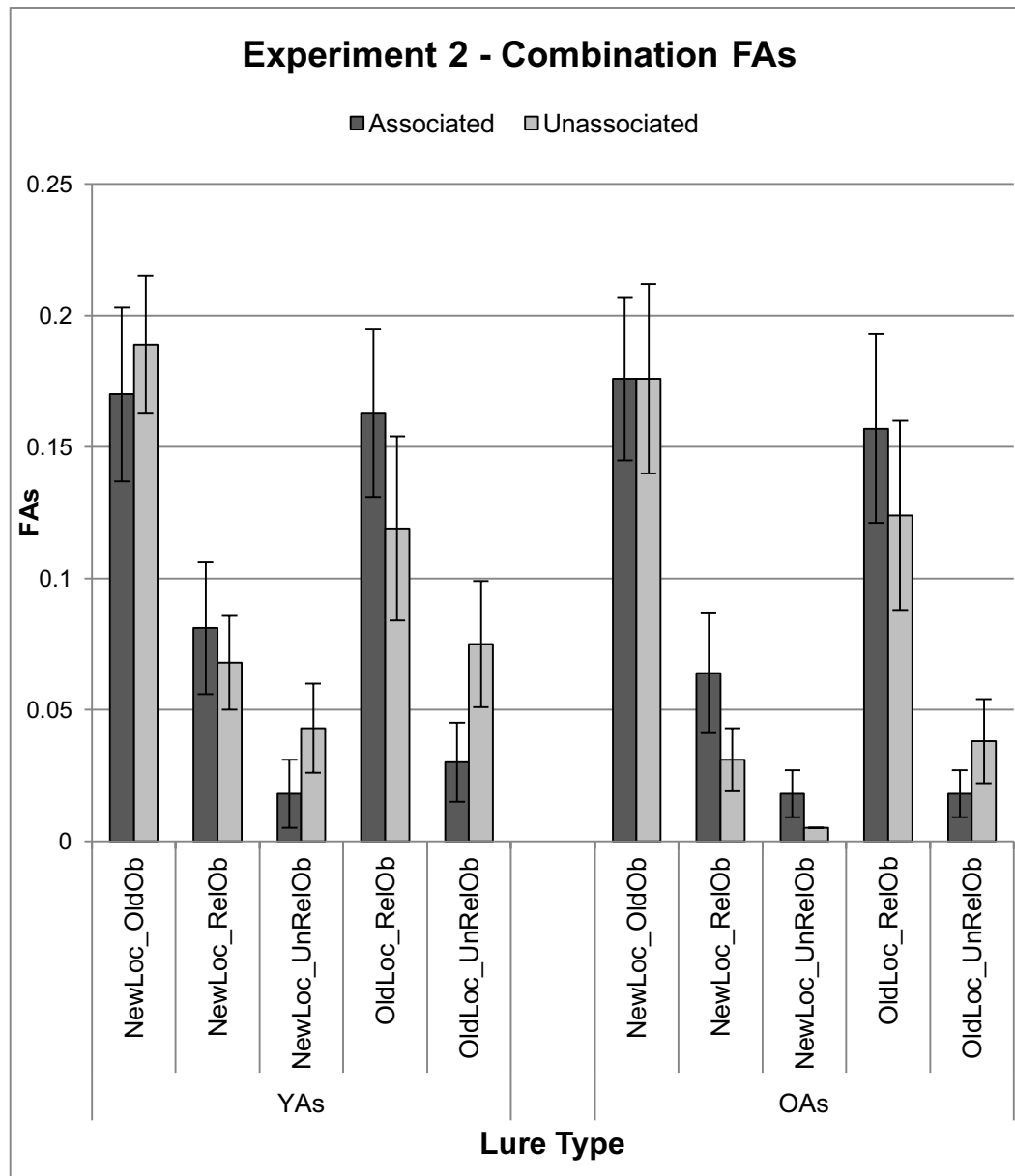
Note. YAs = Younger adults; OAs = Older adults; NewLoc_OldOb = New location old object lure; NewLoc_RelOb = New location related object lure; NewLoc_UnRelOb = New location unrelated object lure; OldLoc_RelOb = Old location related object lure; OldLoc_UnRelOb = Old location unrelated object lure.
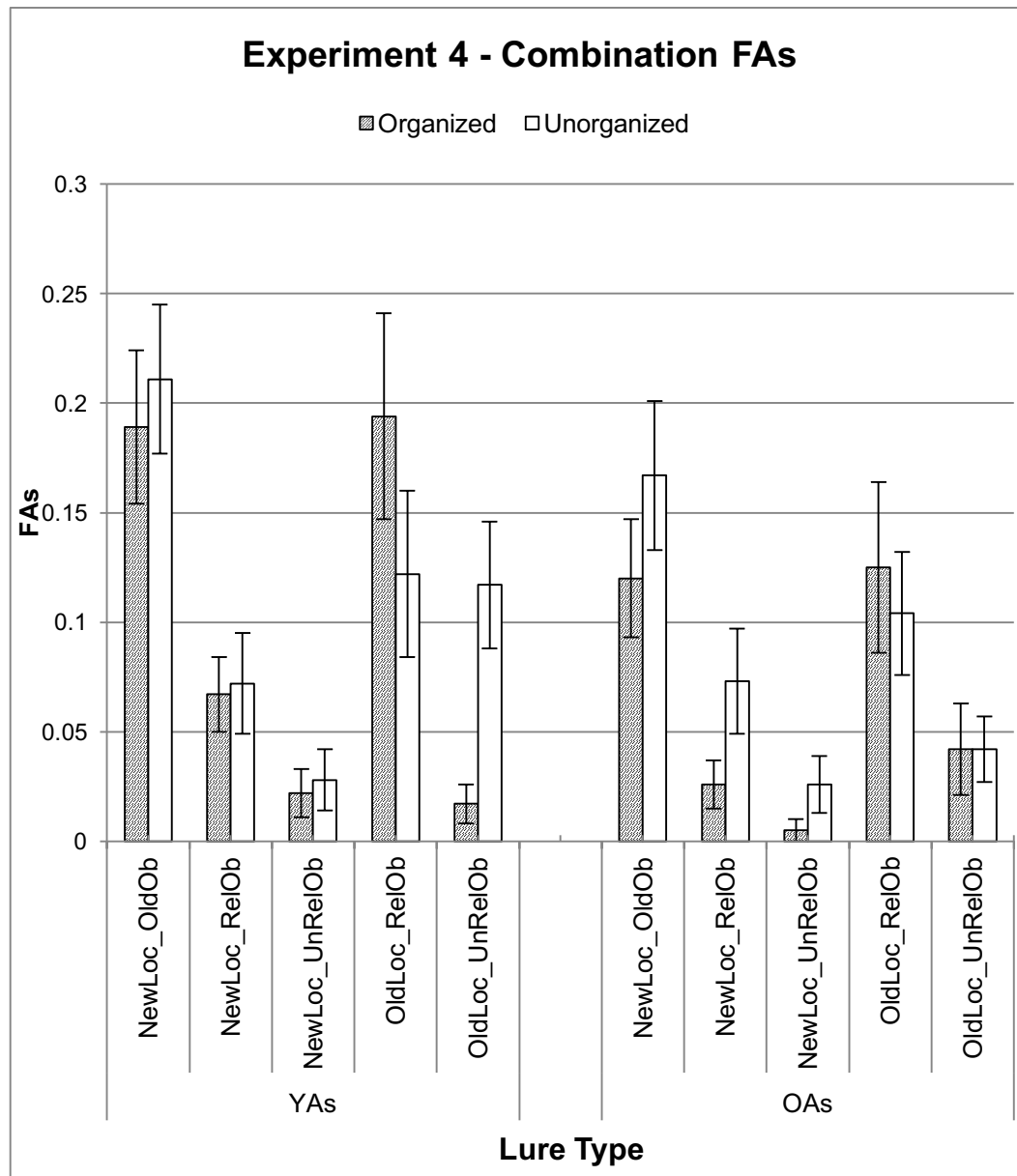
Figure 6.

Note. YAs = Younger adults; OAs = Older adults; NewLoc_OldOb = New location old object lure; NewLoc_RelOb = New location related object lure; NewLoc_UnRelOb = New location unrelated object lure; OldLoc_RelOb = Old location related object lure; OldLoc_UnRelOb = Old location unrelated object lure.
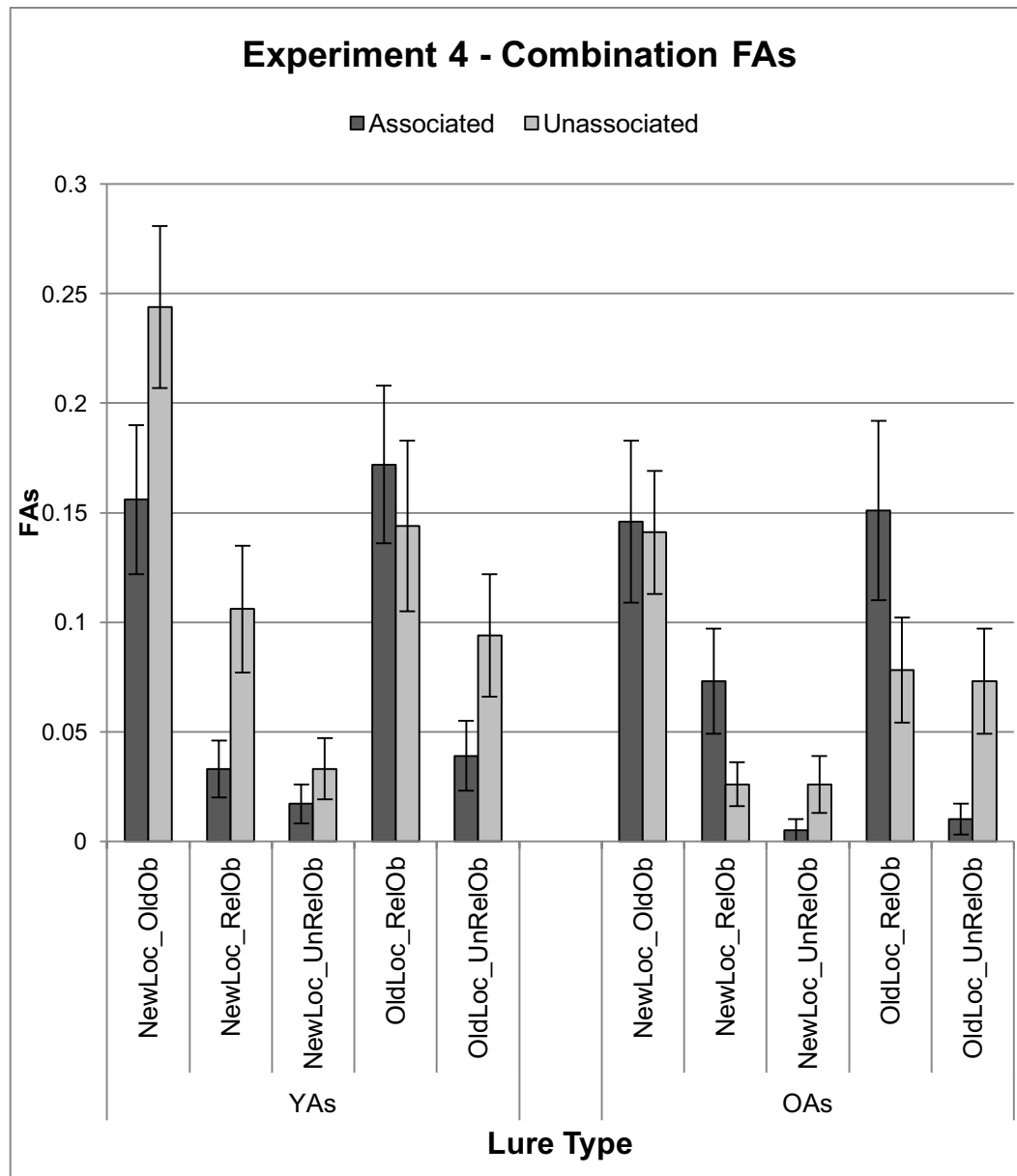
Figure 7.

Note. YAs = Younger adults; OAs = Older adults; NewLoc_OldOb = New location old object lure; NewLoc_RelOb = New location related object lure; NewLoc_UnRelOb = New location unrelated object lure; OldLoc_RelOb = Old location related object lure; OldLoc_UnRelOb = Old location unrelated object lure.

Figure 8.

Note. YAs = Younger adults; OAs = Older adults; NewLoc_OldOb = New location old object lure; NewLoc_RelOb = New location related object lure; NewLoc_UnRelOb = New location unrelated object lure; OldLoc_RelOb = Old location related object lure; OldLoc_UnRelOb = Old location unrelated object lure.

Figure 9.

Note. YAs = Younger adults; OAs = Older adults; NewLoc_OldOb = New location old object lure; NewLoc_RelOb = New location related object lure; NewLoc_UnRelOb = New location unrelated object lure; OldLoc_RelOb = Old location related object lure; OldLoc_UnRelOb = Old location unrelated object lure.

Figure 10.