Age-Related Changes in Online Map Processing

An honors thesis for the Department of Psychology

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Abstract

The ability to extract information efficiently and effectively from maps is a cognitive process that is intimately tied to visual-spatial working memory (VSWM); yet, few studies have investigated the link between map learning and VSWM. The present study represents a first step in filling this gap. Age-related changes to VSWM in the map learning context were also explored in this study as previous research has found that changes to both episodic map learning and VSWM are related to normal aging. (Meneghetti, Fiore, Borella, & De Beni, 2011; Thomas, Bonura & Taylor, 2012). The current study investigated how reliance on location versus identity information changes as a function of age in the context of a VSWM map task. Thirty young and thirty older adults were presented with 104 trials. Trials were structured so that participants studied map-like grids containing five landmarks for three seconds. Immediately after study, participants' memory for landmarks, location of landmarks, or the combination of both the landmark and its location were tested. Spatial organization and semantic relationship within grids were manipulated. Results demonstrated that spatial organization facilitated performance across question types while semantic association did not affect memory to the same extent. Further, older adults were easily biased by both spatial organization and semantic association. Young adults were able to more effectively use spatial organization and semantic association to guide response. These results suggest that location plays a stronger role in map processing than in other similar VSWM tasks.

Introduction

Imagine that you are trying to meet up with a friend at a new restaurant. You have a map on your phone in front of you as you walk towards this new location. This map displays the various landmarks and their associated locations that are near you. In order to navigate through the environment, you cannot continuously stare at your phone as you walk. You look at it, put it away and keep walking, until you no longer remember the route on the map and you take another quick glance at your phone. This process of navigation described is online map processing. It is our ability to interpret map information to make accurate decisions as we simultaneously navigate the environment. Online map processing is highly similar to another important cognitive mechanism, visuo-spatial working memory (VSWM). VSWM is a component of the working memory system that enables us to maintain and manipulate a limited amount of information for a limited amount of time (Baddeley and Hitch, 1974). VSWM applies specifically to the visual and spatial information in our environment, such as a restaurant's location and appearance.

The goal of the current study was to better understand the relationship between online map processing and VSWM. This study transformed a typical VSWM experimental paradigm in order to take a map-learning approach. The purpose of doing so was to compare and contrast processes used in VSWM and map learning. Furthermore, the study was interested in how VSWM and map processes are affected by age, particularly how reliance on various forms of visuo-spatial (VS) information changes with age. Both VSWM and map processing rely on binding, the ability to integrate two forms of information. In both the VSWM and map context, binding integrates an identity, such as a landmark, with its location in space. Due to binding's important role in VSWM and map learning, the current study also explored how aging affected binding of VS information in the map context.

Visuospatial Working Memory. VSWM represents spatial, or location, information, "the where," and semantic, or identity, information, "the what." The efficiency and accuracy of VSWM depends upon our ability to bind these two streams of information (Baddeley & Hitch, 1994). The distinction between location and identity processing has been confirmed in multiple VS studies. Logie and Marchetti (1991) demonstrated the dissociation by presenting participants with an array of colors or a series of squares presented at different points on a screen. Participants then had a retention interval in which they watched a blank screen, performed a spatial tapping task, or looked at line drawings. The spatial tapping task only impacted memory of where the squares had been presented in the first phase of the experiment, whereas the line drawings only interfered with retention of color information within the grid. These findings established the different processes that enable location memory and identity memory. This serves as evidence for the current VSWM test paradigm that location processing and identity processing are distinct cognitive mechanisms within VSWM.

Since Logie and Marchetti (1991), the distinction between location and identity processing has continued to be studied in depth. Regardless of stimuli presented, or type of interference task, the results remained the same. Spatial interference tasks affected location memory performance, while visual interference tasks affected identity memory (Darling, Della Sala, Logie & Cantagallo, 2006; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999). These studies demonstrated, across paradigms, a distinction between location and identity processing and memory. Neuroscientific evidence further supports the behavioral distinction. The dorsal stream, which goes to the parietal lobe, has been found to process location information, whereas the ventral stream which goes to the temporal lobe has been found to be involved in processing of objects (Goodale & Milner, 1992; Mishkin, Ungerleider, & Macko, 1983). These neuroimaging studies provide a biological perspective to the consistent behavioral results of the cognitively distinctive components of VSWM. It is thus well-established, both behaviorally and neuroscientifically, that location processing and identity processing are two separate systems. Parallel processing such as the model described would suggest that each stream is likely governed by different mechanisms. The nature of these two mechanisms and how information from the two processing paths are eventually united, or bound together, such that individuals are able to maintain a unitized representation of objects in the space that they reside, are the focus of the present investigation.

Processing of Spatial Location. While humans need both location and identity information to accurately organize and interpret the environment, this does not entail that both forms of information require the same amount of cognitive resources. Several studies have demonstrated that location information requires less effortful processing than identity information. Johnston and Pashler (1990) asked subjects to respond to location and identity questions of items presented briefly. Participants always responded correctly to identity information if they responded correctly to its location information; however, sometimes they would only remember location information without identity information, and rarely would they correctly respond to identity information without also correctly responding to location information. This suggests that location processing occurred before identity processing, as an initial stage in processing visual information. It required minimal effort compared to processing identities, based on the higher accuracy of location responses and the correspondence with identity responses. The current study examined how location and identity information are processed using various levels of effort based on manipulation of these forms of information. These questions were developed from previous research by Dai, Taylor and Thomas (2015). In the study, participants were shown grids containing objects. The objects were either spatially organized within the grid, or scattered in a random configuration. The objects were either semantically related or unrelated. In their study, it was found that spatial organization of objects within grids facilitated both location memory and object memory.

Taylor, Thomas, Artuso, and Eastman (2014) found that when subjects were shown grids with items organized spatially within the grids, location information was best remembered at test. Furthermore when items were organized in a recognizable pattern, this impaired memory for items in the grid, in contrast to the findings of Dai et al (2015). These findings suggest a focus on location processing could be facilitated by the structure of the task. Task structure influenced prioritization of location processing, resulting in a cost associated with other forms of processing. This location preference was also demonstrated in a similar VSWM paradigm in Thomas, Bonura, Taylor and Brunyé (2012a). Participants were told to study location, identity or both before each question. When asked about identity, location, or the combination of the two, location memory was consistently most accurate, even as the amount of information presented in grids increased. This accuracy with increasing amounts of information was not paralleled on questions asking the identity of objects in the grid, or the object and its location. This robust location processing evidence supports a model of less effortful and prioritized location processing. Further, the research suggests that task structure can influence when and how location processing is engaged. The current study further examined how spatial organization affects location memory, and how it may also affect memory for identity information.

Processing of Identity. In contrast to identity processing, memory for identities has been proposed to require more effortful processing (Taylor et al., 2014; Thomas et al., 2012a). Identity memory refers to the entity that is being represented in space at a specific location. In many VSWM tasks, identity information is represented as an object or symbol. The current study used landmarks found on maps as identity information. Thomas et al (2012a) found that object memory became less accurate with a changing amount of information inside of the grid due to higher working memory demand, while location memory remained constant. Thus the general relationship between location and identity processing that has been found is that while location memory is relatively consistent; identity memory is not as efficient and requires more effort to maintain. Taylor et al (2014) found that identity memory became less accurate when information was spatially organized, suggesting that identity memory required additional cognitive resources that were not available after preferential location processing. The current study explored how changes to the presented identity information could make the processing of identity information less effortful and more accurate.

While requiring more central effort, semantic representations of identities in VSWM are nonetheless important for accurate memory processes. Dai et al (2015) found that when subjects were shown semantically related objects in a grid, their memory of the objects within the grid improved. Furthermore, semantic association also improved general memory performance, suggesting it enhanced location memory, just as location memory facilitated identity memory. Dai et al (2015) also found that identity memory could be biased by lures that were semantically related to previous objects studied. Thus subjects actively processed and used representations of semantic association between objects to aid in recognition. These lure data also demonstrated that identity information processing does not solely rely on the processing of location information, it is independently processed for WM accuracy.

Semantic association in non-WM tasks has also been found to play a role in location processing (Hirtle & Mascolo, 1986; Thomas, Bonura, & Taylor, 2012b). In Thomas et al (2012b) subjects were asked to do a free recall of previously studied maps that contained either semantically organized or unorganized landmarks. Subjects recalled more landmarks in semantically organized maps than unorganized. Furthermore, the semantically organized maps affected location processing. Subjects placed semantically related items significantly closer together than they appeared on the map. This provides further evidence that semantic association and organization on memory tasks facilitate both identity and location memory. The current study examined whether this effect can be replicated in a map study that uses a VSWM paradigm.

Aging and VSWM. The processing of location and identity information does not remain consistent throughout aging. Salthouse, Babcock, Skovronek, Mitchell and Palmon (1990) found through a series of batteries testing for location processing that older adults consistently performed worse on these tasks than young adults. These differences persisted in older adults who had long-term careers that required strong location processing skills. Thus this age-related decline in location processing is a pervasive cognitive change. Several other studies provide further evidence for age-related deficits in location processing (Dollinger,1995; Meneghetti et al, 2011). Conversely, identity memory seems to be a more preserved mechanism. Wilkniss, Jones, Korol, Gold, and Manning (1997) found that the accuracy for remembering landmarks on a route learning task was high in older adults; however, decreased location accuracy and difficulty binding location and landmark information resulted in overall poor performance in the learning task. Chalfonte and Johnson (1996) also found decreased location accuracy and preferential featural processing in older populations on a VSWM task, as compared to younger adults. From this evidence, we expected that in the current study, older adults would over-rely on identity information to guide response.

Research also demonstrates that older adult memory performance in VS tasks can be improved if they are given direction as to what to study. Thomas et al (2012b) found that older adults were not able to make use of related semantic information to facilitate memory processing. However, when they were explicitly told to make use of semantic associations on presented material, their results paralleled that of younger adults. This relates to Thomas et al (2012a), in that the older adults performed well once they were told to either study location, identity or both forms of information and thus made use of strategic processing. In both studies, specific instructions were needed to inform strategic processing. This supports the theory proposed by Craik (1991) that older adult memory can be improved with instruction as to what to process. Without explicit instruction older adults will not know how to ease the cognitive demand of the task. Thus it is that older adults have difficulty in processing VS information, or that they have difficulty strategically processing information in general. The current study will focus the former possibility in examining what processes are preserved and what processes are changed as a result of aging in VSWM.

These studies present a dissociation of location and identity processing abilities in older adults. While older adults have decreased location processing abilities, research suggests identity processing remains intact and could potentially be used as a scaffold for recognition in the current study.

Binding. VSWM does not simply rely on the two distinctive components of location and identity memory to elicit accurate memory. The accuracy and efficiency of VSWM depends upon our ability to integrate the two streams of information in a process known as binding. While the current study investigated location and identity processing separately, the ability to bind information and how this ability changes with age is also highly relevant to the study. The majority of questions that subjects responded to were questions concerning the binding of location and identity map features. We placed such importance on the ability to bind information because both VSWM and map processing rely on binding processes to make quick judgments in the environment.

Much attention in psychological research has been devoted to the question as to how this binding process occurs. Johnston and Pashler (1990) found that when subjects responded to location and identity questions based on an image shown, they tended to answer both questions correctly or both wrong. This suggests that the two types of information were immediately bound to form a single representation in VS memory. In the current study, we questioned the ease at which one could bind complex forms of information into a single, yet more complex item, and what factors affected the efficiency of binding. Treisman and Gelade (1980) first discussed the importance of attention in binding features. It was proposed that in order to bind location and identity features, location processing needed to occur before the binding of the two forms of information. Then, to remember appropriate identity information and to bind it with the appropriate location information, central attention was need (1980). Essentially, encoding location, a less effortful process, is needed in order to bind information using more central processes. This theory has important implications for the current study as questions requiring binding mechanisms were dependent upon both spatial and semantic manipulations. Several studies have supported and further examined Treisman's theory of attention's role in feature binding (Hyun, Woodman & Luck, 2009; Shen, Huang & Gao, 2015; Zokaei, Heider & Husain 2014). These more recent studies provide evidence that binding requires more central effort while the encoding of individual features is more automatic. For example, in Shen et al (2015), after completing an interference task, subject's memory for individual features of presented material remained was highly accurate whereas their memory for the binding of these features was significantly less due to the interference task. Hyun et al (2009) used ERP as well as reaction time and accuracy data to examine the differences in attention needed to correctly bind location and identity features. Larger ERPs were found when subjects were asked to determine the location and identity of previously shown stimuli, as opposed to being asked if a stimulus had been presented, demonstrating more attentional effort was used for responses requiring binding. This study provides neurological support to behavioral evidence on the use of attention in binding. The current study further explored how binding accuracy differed from memory of individual features. We were also interested in how the cognitive resources used in binding can be lightened by organizing landmarks in clear spatial patterns and making the landmarks semantically related.

Research has also explored how attention to location information impacts binding ability. Taylor et al (2014) tested how binding accuracy changed based on the spatial organization of grids in their VSWM task. Participants were told to focus on locations or objects and were then shown an updated grid and asked whether it was the same grid or different. It was found that in conditions when subjects were asked to process location information, thus allowing subjects to use strategic processing, this increased their memory of both location and identity information. This implies that the smaller amount of cognitive resources used at encoding led to more effective processing of both types of information and binding of them. This study demonstrates that binding is influenced by other factors not explicitly related to the VS context as strategic processing led to increased binding performance. The current study explores what types of conditions lead to most efficient and reliable binding of information, and how these conditions may also lead to biased responding.

These binding questions that guided the current study were adapted from Dai et al (2015). This study found that when grids were spatially organized, accuracy on binding questions was improved regardless of strategic processing. Similar to Taylor et al (2014), these results suggest that location processing may play a larger role in the binding of location and identity information, or at least frees cognitive resources in order to better enable binding processes to occur. The current study used the same basic design of this study to examine how spatial organization and semantic association affect binding in online map processing. While spatial organization facilitates binding processes in this context, we were also interested as to whether this form of organization would facilitate binding in the map context.

The current study was not only focused on what enhances or detracts from binding abilities as a function of information presented on the grid, but also how binding processes change as a function of age. Several studies have examined age-related effects on binding information. Age-related binding deficits in VSWM have been found in several studies (Chalfonte & Johnson, 1996; Cowan, Naveh-Benjamin, Kilb, and Saults, 2006; Thomas et al., 2012b). In Thomas et al (2012a), it was found that older adults performed similarly to younger adults on a VSWM task when they were given more time to study the test grids. Yet regardless of study time, they consistently performed worse than the young adult group when asked about the combination of both location and identity information. While this evidence points towards an age-related binding deficit, other aging studies have not found a binding-specific deficit in VSWM paradigms (Brockmole, Parra, Della Sala, & Logie, 2008; Brown & Brockmole, 2014). Dai et al (2015) found a main effect of age across all question types. There was no interaction between binding questions and age, demonstrating that while there was an aging deficit, it was not specific to binding. These results align with Brockmole et al (2008), Brown and Brockmole (2014) as well as other aging studies arguing that the binding of VS information is not an age-related deficit (Bopp & Verhaeghen, 2009).

One reason for this discrepancy may be explainable by neurological research. In Meier, Nair, Meyerand, Birn, & Prabhakaran (2014), similar results were found to Dai et al (2015) on a VSWM task. Given a VSWM task, there was a main effect of age, and no specific interaction between age and binding questions. However, using brain imaging data, there were significant differences in brain activity between age groups during binding trials. These results suggest that older adults do have deficits in handling more cognitively demanding tasks but the neural differences may not lead to significant behavioral changes in performance in the experimental setting. Mitchell, Johnson, Raye, and D'Esposito (2000) found both neurological differences in a VSWM tasks between older and younger adults as well as performance deficits; both sets of results specific to questions requiring binding. This study supports both the findings of Meier et al (2014), and Thomas et al (2012a) in that it found both neurological and behavioral differences that were specific to binding abilities. For the studies in which binding questions did not have an interaction with age, it is imaginable that binding differences could become more apparent in a non-controlled setting. In a non-controlled setting, several other influences surrounding the person would use cognitive resources as well, and would thus take away from the resources necessary to effectively bind information. Furthermore, the stimuli used across these studies were inconsistent and the manner in which participants were tested varied as well, thus the studies may not be comparable. The current study contributed to the current debate on the age-related deficits, or lack thereof, in binding.

Processing Map Information. The VSWM studies discussed have all been limited to studies of grids or images. In the current paradigm, the grids used in Dai et al (2015) were replaced with analogous navigational maps. The primary interest was in determining whether the same processes that govern VSWM would operate when studied information takes the form of maps as opposed to abstract grids. Previous research suggests that map processing relies on VSWM. For example, in one study, subjects memorized various map routes, studied nonsense words and then performed some type of interference task before being tested on map and nonsense word memory. Verbal interference tasks disrupted map memory providing evidence for the role of an identity processing in map learning (Garden, Cornoldi & Logie, 2002). These results demonstrate that map learning and VS processing may share cognitive mechanisms allowing people to extract appropriate location and identity information to complete a task. This evidence guided the current study towards the understanding that map processing and VSWM would use similar mechanisms to influence memory accuracy. Collucia (2008) made use of a spatial interference task to examine location processing in VSWM using a map learning context as opposed to previous studies using a more standard paradigm of objects in grids (Della Sala et al., 1999; Logie & Marchetti, 1991). Collucia (2008) found that a spatial tapping interference task disrupted the learning of landmark positions in relation to other landmarks, and without the influence of other landmarks, as well as following routes between landmarks. This disruption occurred regardless of a verbal interference task demonstrating a stronger dissociation between verbal and VS working memory processes. However, this study did not discuss the potential impact of verbal interference on remembering landmark identity, which could have provided more insight about the role of semantic information in map learning.

Map processing research also focuses on how semantic biases affect map memory. For example, Stevens and Coupe (1978) found that people are more likely to judge Montreal as being north of Seattle, which is not true, as Seattle is actually more north. However, people's organizations of facts, such as Canada being north of the United States, led to faulty judgement on map tasks which require the integration of identity information (landmarks) and spatial relationships. Tversky (1981) identified this form of memory biasing as an alignment effect, in which humans perceive familiar figures on maps based on their general relationship to each other, such as South America being below North America, which can then bias judgment of specific location on a map. Tversky (1992) proposed that these distortions of memories are due to the way by which we organize map information in hierarchical semantic categories, more so than as spatial representations. Humans naturally organize landmarks on a map into groupings based on categorical information, such as geographic categories or semantic categories (Curiel & Radvansky, 1998). These categories then influence how a map is represented in the mind. The current study sought to better understand the effects that spatial categorical information and semantic categorical information have on each other during the processing of maps and how these effects may be altered with the use of a VSWM task as opposed to a long-term memory (LTM) task.

The roles of location and identity processing in map learning is highly relevant to the current study as it explores how one form of processing can bias another form of processing in a map learning context. Thomas et al (2012b) provides further insight into these influences of categorical representations on mental models. Semantic association led to better performance on the free-recall task for landmarks, thus demonstrating a direct relationship to identity memory in map-learning. Furthermore, these semantic associations affected where subjects remembered the landmarks were located. This illustrates that semantic associations within maps influence binding processes to the degree that they bias memory towards one type of information being bound. As the current study was designed to understand how both semantic association biases location memory, and how spatial organization biases semantic memory in the map learning context, Thomas et al (2012b) demonstrate the processing, and representations of one form of information can bias the processing of another form of information.

Thomas et al (2012b) is also highly relevant to the current study as it also measured how aging affected map memory. As stated previously, it was found that older adults needed explicit instruction to take advantage of semantically related landmarks to facilitate memory on a free recall task of a previously presented map. Thus, there are some age-related changes in processing of VS information in a LTM task. Wilkniss, Jones, Korol, Gold, and Manning (1997) also found impairment in older adults to appropriately apply perceived information to map learning. When asked questions about landmarks on a learned route, older adults had difficulty remembering where they saw a specific landmark. While landmark information was remembered, its corresponding location information was not effectively encoded. Ultimately older adult subjects could not use landmarks as cues for location information. This impaired location processing in environmental contexts has also been found in Kirasic (1992) and Lipman and Caplan (1992). Thus age-related deficits in location memory that are found in VSWM are also found in a map-learning context, providing evidence for the study's hypothesis that VSWM and map processing have intimately tied cognitive processes. Further evidence for this relationship was found by Meneghetti et al (2011) who found that map memory in older adults was highly related to their decreased VS skills, tested separately from map learning. The two reasons for performance differences, VSWM and spatial processing deficits, are not mutually exclusive and it may be that with decreased VS functioning, older adults need more scaffolding to succeed in a VSWM task. The current study addressed what VS information is most relevant to older adults in map processing, and how this is different or similar to the types of information young adults use to process VS information.

The Present Study. The current study examined how the various processes underlying VSWM are related to processes involved with map learning and how they change as a function of age. Location, identity, and binding processes were studied in the map learning context through the analysis of patterns of correct and incorrect judgments of participants and how these patterns changed with age. Participants were presented with a map-like grid for a brief period of time. Each grid contained five landmarks. The landmarks were semantically related on half of the grids, and all unrelated on the other half. The landmarks were organized in a clear spatial configuration for half of the trials, and unorganized in the other half. Using this design, we were able to test for effects of spatial organization and semantic relationship on various VSWM and map learning processes. After seeing a map, participants were then asked to make a judgment of learning (JOL) about how likely they were to remember the information presented. They then were asked a question about the location of a landmark, identity of landmark or both the location and identity of the landmark.

We predicted that spatial organization of landmarks would have the strongest positive impact on memory processing for all three aspects of VSWM. We predicted semantic relationship would have effect all three aspects to a lesser degree. In terms of aging effects, we predicted that young adult accuracy would increase with spatial organization whereas older adult performance would be facilitated by semantic association.

Methods

Participants. Thirty young adults (23 female and 7 male) and thirty older adults (20 female and 10 male) participated in this study. Young adults ranged from 17 to 21 years of age (*M* =18.41, *SD*= 0.87). All were undergraduates at Tufts University and received a course credit for participating in the study. Older adults were between the ages of 57 and 81 (*M* = 69.37, *SD*= 5.90). They were recruited using the Tufts Cognitive Aging and Memory Lab's participant pool. Older adults were compensated 15$ for their participation.

Design. This study used a 2 (Semantic Association: *Related, Unrelated*) x 2(Spatial Organization: *Organized, Unorganized*) x 3 (Question Type: *Location*, *Identity*, *Combination*) x2 (Age: *Young Adults, Older Adults*) mixed design. Semantic association, spatial organization, and question type were within-subject variables and age was a between-subject variable.

Materials: Stimuli consisted of map-like 5x5 grids consisting of common locations, or landmarks, found in cities in the U.S. Landmarks were divided in 13 semantic categories, such as education establishments. Each category contained eight general landmarks. For example, within the education category, landmarks included preschool, charter school and public university. This resulted in a total of 104 landmarks. Category membership was determined through pilot testing. Fourteen participants were given the 13 category headings, and asked to list as many exemplars within each category as possible. The top eight responses from each category were chosen as stimuli. See Appendix for the list of all categories and landmarks. See Table 5 in the appendix for a list of all categories and associated landmarks.

Study Grids. One hundred and four 5 x 5 study grids were prepared for the study. Grids were designed to simulate a city map. Five landmarks appeared on each grid as a red square with a label underneath. The exact location of the squares in the block was randomized from grid to grid. Half of the study grids were spatially organized. On spatially organized grids, landmarks were arranged in a clearly identifiable configuration, such as making an L-shape on the grid or a straight horizontal line. The other half of the study grids were unorganized; landmarks were scattered at random, avoiding any possible pattern configuration. Half of the grids were also semantically related. On semantically related grids, the five landmarks on the study grid were drawn from the same semantic category. On the semantically unrelated grids, each landmark was drawn from a different semantic category. Thus, the study grids were divided into four categories evenly: 26 Organized-Related, 26 Unorganized-Related, 26 Organized-Unrelated, and 26 Unorganized-Unrelated. See figures 1, 2, 3 and 4 for examples of each grid type. Out of 104 grids, each landmark was used at least four times and no more than six times. A specific landmark was never used in the same location on multiple grids. On unorganized trials, a location was used no more than twelve times across related and unrelated grids. On organized trials, a spatial layout (e. g., an X) was used twice on related (always with a different category), and twice on unrelated grids. The exact same group of five landmarks was never used on more than one grid. That is, in the case of semantically related trials, a unique group of five landmarks from a given category were chosen for each organized grid, and another group of five from the same category was used in each of the unorganized grids. Because there were only eight items in each category, there was some overlap. However, the above constraints were maintained.

Test Grids. For each studied grid, eleven possible test grids were created. Two test grids contained questions about the location of a landmark; three contained questions about the identity of a landmark, and six contained questions about the combination of both the location and the identity. Of the 104 test grids presented to subjects, 26 were location questions, 26 were landmark identity questions and the remaining 52 were combination questions. For location test grids, a blank grid with a square was created. The square, with same dimensions and color as those of the study grids, represented a location that was used on a study trial (studied location), or not used (foil location). All locations were used an equal number of times across test grids, and within a grid type, no block was used as a study location or foil location more than once. At the bottom of each location test grid, was the question "*did you study a landmark at THIS location?"* Eight location questions contained the correct information, the remaining 18 were lures. See Figure 5 for an example of a location test grid.

Identity test grids presented the name of a landmark. The presented landmark was either previously studied (studied landmark) or not (foil landmark). There were two types of foils, one containing landmarks from the same semantic category of a related study grid, or that shared a category with one landmark on an unrelated grid (related foils), the other containing landmarks from a semantic category not represented in the previous study grid (unrelated foils). For all identity test grids, the bottom of the display contained the question "*did you study this landmark?"* Eight of these questions contained correct information, nine were unrelated lures, and nine were related lures. See Figure 6 for an example of a landmark identity test grid

Lastly, there were combination test grids. There were five types of foil test grids created for each study grid, as well as a test grid with the correct information. The grid could contain a new location and an unrelated landmark (NL-UI), new location and related landmark (NL-RI), a new location and an old landmark (NL-OI), an old location with an unrelated landmark (OL-UI), and lastly an old location with a related landmark (OL-RI). The bottom of combination test grids contained the question "*did you study THIS landmark at THIS location?"* Twelve combination questions contained correct information, and there were 8 questions for each lure type. Examples of lures can be found in Figures 7-11.

To ensure that participants answered recognition questions conservatively, only 28 of the questions had the correct answer of "yes", and the remaining 76 questions were lures. The amount of false alarms and hits varied between counterbalances by one to two questions but the differences between the three counterbalances were extremely minor. The high percentage of lures also allowed for examination of various kinds lure susceptibility.

Vocabulary Tests and Questionnaires: Young and older adults completed a synonym vocabulary test at the end of the study (Shipley, 1946). Older adults also completed a Mini-Mental State Exam (Mini Mental State Exam; Folstein, Folstein, & McHugh, 1975).

Procedure. The study was created using e-prime software and was presented on a standard personal computer. Participants first saw instructions. After informed consent, participants were instructed that they would study and be tested on individual maps. Instructions were followed by a practice phase, which consisted of three trials. On a given trial participants would be presented with a grid, were asked to predict how likely they would be to remember information on the previous grid, and then be tested on the grid. Studied grids were presented for 3 milliseconds to both age groups after pilot studies demonstrated that older adults did not need extra time. After the presentation of the study grid, participants made a judgment of learning (JOL) prediction, as used in Thomas et al. (2012a). Participants answered the question *"how likely do you think you would be to recognize the information shown in the grid?"* using a Likert scale of 1 to 10 with 1 as "*not likely at all to recognize*" and 10 as "*extremely likely to recognize*". Following the JOL, participants then answered a yes/no recognition question about the map presented. To respond to the recognition question on each test grid, young adult participants were instructed to press the "A" key for *yes* and the "K" key for *no*. The experimenter recorded responses for older adults in order to control for the response time between older and younger participants, as older adults were not as comfortable using computer keyboards as the younger adults. The practice grids were all unorganized, unrelated maps with landmarks not used in the experimental tests. Three practice trials were presented corresponding to the three types of test questions (landmark identity, location, or combination). Following practice, participants were given the opportunity to ask questions, and then the experimental session began. After all 104 grids were presented, all participants input demographic information through the e-prime program. Older adults verbally stated their responses and the experimenter input the response to the e-prime program, since many older adults were not comfortable with typing words accurately through the computer keyboard. All participants completed the vocabulary test using a pen and paper. Older adults also completed the Mini-Mental State Exam, as led and scored by the experimenter, to confirm there were no abnormal cognitive deficits.

Results

Results were calculated using hits, false alarm and d' analyses. Location and identity trials were analyzed together, and combination trials were analyzed separately, due to the more complex nature of these trials. All statistical comparisons were significant at the .05 level, except for planned comparisons using t-tests that were corrected for alpha inflation using a Bonferroni correct.

Location and Identity Results: d' analysis. Recognition accuracy was computed using d prime (d') to examine participant performance based on the difference between ability to correctly identify previously presented information (hits) and incorrectly identifying lure information (false alarms). D' analyses used a 2 (question type) x 2 (spatial organization) x 2(semantic association) x 2(age) mix-factored ANOVA. The ANOVA revealed a main effect of age [$F(1, 58) = 9.648$, $p < .005$, $np^2 = .14$], in which younger adult performance ($M = 3.16$) was better than that of older adults ($M = 2.58$).

It was predicted that spatial organization would facilitate memory processing and would thus have positive effects on both location questions and identity questions. A main effect of spatial organization [$F(1, 58) = 96.21$, $p < .001$, $np^2 = .62$] supported this hypothesis. The ANOVA also revealed a two-way interaction of spatial organization and question type [$F(1, 58) = 27.47$, $p < .005$, $np^2 = .32$], demonstrating that spatial organization had a greater positive effect on location questions ($M = 4.00$) rather than identity questions ($M = 3.18$), $t(29)=3.49$, p = .001. See Table 1 for location trial accuracy means and Table 2 for identity trials. There was also a marginal two-way interaction of spatial organization and age [$F(1, 58) = 3.714$, $p = .059$, $np^2 = .06$], which suggested that correct response by older adults was driven by spatial organization more than in young adults. This contradicted the original hypothesis that older adults would not use spatial organization to guide response. A three-way interaction between spatial organization, question type, and semantic information illustrated further the impact of spatial organization on accuracy [$F(1, 58) = 9.55$, $p < .005$, $np^2 = .14$]. A paired-samples t-test was computed to investigate the role of spatial organization in the interaction. On location questions, spatial organization aided performance when grids were related [$t(59)=5.82$, p < .001] and unrelated [$t(59) = 8.31$, $p < .001$], as compared with unorganized grids. On identity questions, spatial organization, when compared to unorganized grids, also led to higher accuracy when the grids were related [$t(59) = 4.66$, $p < .001$]. However, for identity questions in which grids were unrelated, spatial organization did not affect accuracy [$t(59) = -0.67$, $p = .50$]. Thus spatial organization held an important role in memory accuracy when asked about location, regardless of semantic relationship of landmarks on the grid, although on identity questions, spatial organization only facilitated memory processes when grids were semantically related. This also implicated that semantic association played a role in memory accuracy, as it interacted with spatial organization such that when both were present, memory was highly accurate.

Semantic association was also predicted to increase memory accuracy across location and identity questions. Contrary to this prediction, no main effects of semantic association were revealed by the ANOVA. However, there was a marginal three-way interaction between semantic association, spatial organization and age [$F(1, 58) = 8.77$, $p = .077$, $np^2 =.05$]. Thus semantic association did play some role in memory accuracy through its interaction with spatial organization and depending on the age group.

Hits. Additionally, we examined hits and false alarms in separate analyses. To analyze hits, we calculated a 2 (spatial organization) x 2 (semantic association) x 2 (question type) x 2 (age) ANOVA. This ANOVA revealed a marginal main effect of age [$F(1, 58) = 3.83$, $p = .055$, $np^2 = .06$], a marginal main effect of question type demonstrating higher accuracy on identity questions [$F(1, 58) = 3.97$, $p = .051$, $np^2 = .06$], and lastly a main effect of spatial organization [$F(1, 58) = 43.86$, $p < .001$, $np^2 = .43$]. There was also a two-way interaction of spatial organization and question type [$F(1, 58) = 18.06$, $p < .001$, $np^2 = .24$]. This demonstrated that spatial organization had a stronger influence on location questions and less of an effect on identity questions. See Table 1 and Table 2 for hits data on location and identity trials respectively.

In relation to the second hypothesis, that semantic association would have a positive effect on memory, a marginal interaction of semantic association and question type revealed some reliance on semantic information [$F(1, 58) = 2.99$, $p = .089$, $np^2 = .05$]. While semantic association did not affect performance on location questions, semantically related grids did improve accuracy on identity questions.

False Alarms (FAs). Participant errors can often lead to more precise depictions of underlying processes rather than correct responses. The false alarm data used in these analyses were computed by scoring the number of times participants incorrectly judged that they previously saw information presented on the test grid on its associated study grid. This was a measure of subject's susceptibility to lures, created for each question type as discussed in the methods section. ANOVAs for false alarms were computed separately for each question type due to the distinct nature of lures associated with a particular question type.

Location False Alarms. Location questions only had one possible lure type, new location. It was predicted that participants were more likely to false alarm on location questions when grids were unorganized. The ANOVA analyzing location questions used a 2 (spatial organization) x 2(semantic association) x 2(age) design. Our prediction was confirmed by a main effect of spatial organization [$F(1, 58) = 48.63$, $p < .001$, $np^2 = .46$] . Participants false alarmed more frequently when the grids were unorganized ($M = .25$) rather than organized ($M = .10$). See Table 1 for false alarm means.

Identity False Alarms. Identity false alarms were different from location in that there were two possible lure types, related or unrelated lures. We predicted that subjects were more likely to false alarm when map landmarks were related and they received a related lure at test. A 2(spatial organization) x2 (semantic association) x 2(lure type: *related, unrelated)* x 2(age) ANOVA was computed. See Table 2 for identity false alarm means, separated by lure type. There was a main effect of lure type [$F(1, 58) = 48.37$, $p < .001$, $np^2 = .46$]. Regardless of the semantic association of landmarks on the study grid, participants false alarmed more frequently when lures were related to at least one item on the study grid.

There was also an interaction of semantic association and lure type [$F(1, 58) = 17.56$, $p < .001$, $np^2 = .23$]. When grids were semantically related, participants false alarmed more frequently when the lure was related (*M* =.35) rather than unrelated (*M* =.10). This difference was shown to be significant by a paired samples t-test [$t(59)=7.46$, p < .001]. For unrelated grids, participant false alarm rates were similar regardless of lure type. A paired samples t-test verified that these false alarm rates were not significantly different [$t(59)=1.83$, p = .07]. This interaction demonstrated that awareness of the semantic category of a grid led participants to appropriately reject unrelated lures, but made it less easy to reject related lures. When grids were unrelated, they were less susceptible to false alarm, but it was also more difficult to reject unrelated lures.

There was also a two-way interaction of semantic association x spatial organization [$F(1, 58) = 16.64$, $p < .001$, $np^2 = .223$]), see Figure 12. When grids were related, spatial organization facilitated appropriate rejection of lures (*M* =.16). However, when there was no spatial organization, false alarm rates increased (*M* =.283). Using a paired samples t-test, the difference in these false alarm rates between organized-related grids and unorganized-related grids was found to be significant [$t(59)=-3.29$, p < .01]. Conversely, when grids were not related, participants false alarmed more frequently when grids were organized (*M* =.236) rather than unorganized (*M* =.164). A paired samples t-test confirmed a significant difference between these results as well [$t(59)=2.13$, p = .03]. From this interaction, it was observed that participants false alarmed the least when the study grid presented was both spatially organized and semantically related, or when the study grid was unorganized and unrelated. When only organization or association was present, biased responding was induced.

Lastly, there was a 3-way interaction of age, spatial organization, and semantic association for identity lure trials [$F(1, 58) = 11.00$, $p < .01$, $np^2 = .159$]. To examine the effects of age, a paired samples t-test was computed separated by age. It was found that young adult results mirrored the two-way spatial by semantic interaction. In comparing the effects of organization, young adults were more accurate when grids were organized and related rather than unorganized and related [$t(29) = -4.20$, $p < .001$], or when grids when grids were unorganized and unrelated, rather than organized and unrelated [$t(29) = 3.43$, $p = .002$]. Older adult false alarm rates were not related to spatial organization on related grids [$t(29) = -0.94$, $p = .35$] or on unrelated grids [$t(29) = -3.8$, $p = .71$]. This demonstrates that older adults were not able to effectively use map organization or association to appropriately reject lures. However, unlike young adults, they did not over-rely on one representation of map information to guide response.

Combination Results: d' prime and hits analysis. Results from combination question trials were analyzed in the same way as location and identity questions. Combination questions were analyzed separately from location and identity questions due to the large quantity of lures and the more complex nature of binding. It was predicted that spatial organization would increase memory accuracy. A 2 (spatial organization) x 2 (semantic association) x 2 (age) ANOVA using d' scores was conducted to examine accuracy on combination trials. See Table 3 for d' and hits means. The ANOVA revealed a main effect of spatial organization [$F(1, 58) = 3.87$, $p = .054$, $np^2 = .062$]. Spatially organized grids facilitated performance on combination questions, confirming our hypothesis that spatial organization would facilitate binding processes. The ANOVA computed with hits data also demonstrated this main effect [$F(1, 58) = 7.81$, $p < .01$, $np^2 = .119$]. Both of these results confirm the hypothesis that spatial organization positively impacts memory performance. Unlike the hits analysis, the d' analysis also revealed an interaction of age and spatial organization [$F(1, 58) = 4.56$, $p = .04$, $np^2 = .073$]. This interaction, driven by false alarm data, illustrates that older adults were not able to make use of spatial organization to aid in memory (organized: $M = 2.49$, unorganized: $M = 2.51$) whereas younger adults effectively used spatial organization to guide accurate response (organized: $M = 3.19$, unorganized: $M = 2.52$). A paired-samples t-test was computed for this interaction using the false alarm data. On individual item questions, older adults relied heavily on spatial organization for response accuracy, however a different pattern arose with complex information processing involved in binding spatial and semantic information.

Combination false alarms. It was predicted that participants would false alarm the least when the presented lure was a new landmark in a new location (lure: NL-NI), as none of the information presented would have been on the studied grid. NL-NI consisted of the two lure types: new location, related identity and new location, unrelated identity. In these two conditions, false alarm rate was nearly at floor and the two conditions did not differ significantly from each other, thus they were computed as one variable. Besides the hypothesis concerning NL-NI lures, it was expected that participants would false alarm the most when the lure was an old location and related landmark (OL-RI). A 2 (spatial organization) x 2 (semantic association) x 2 (age) x 4 (lure type) ANOVA was computed. There were two main effects. There was a main effect of age, demonstrating that older adults false alarmed more often than young adults [$F(1, 58) = 5. 20$, $p = .026$, $np^2 = .082$]. There was also a main effect of lure type [$F(1, 58) = 28.96$, $p < .001$, $np^2 = .333$]. Paired-samples t-tests were computed to examine the differences between each lure type. There was no significant difference in false alarm rates between NL-OI lures ($M = .227$) and OL-RI lures ($M = .204$), which both drove the highest false alarm rates [$t(59)=.675$, p = .5]. The differences between all other lure types were highly significant. The paired-samples t-test revealed that NL-NI lures led to the lowest false alarm rate (*M*=.037), which was significantly different from OL-UI lures containing the second lowest false alarm rate (*M* =.071), *t*(59)=-2.55, p ≤ .01. The difference between OL-UI lures and OL-RI lures was highly significant, demonstrating that related identity lures strongly impacted lure susceptibility [*t*(59)=5.62, p < .001]. The difference between NL-NI (*M* =.037) and NL-OI (*M* = .227) was highly significant, further emphasizing the importance of semantic processing in binding [*t*(59)=7.57, p <.001]. Interestingly, there was also a significant difference between NL-OI and OL-UI lures (*M* =.071), *t*(59)=6.25, p < .001. These lures are essentially opposites of each other, the first contained a completely new location, and the second contained a completely new landmark. It was the consistent landmark identity in the NL-OI lure that drove higher rates of false alarms, rather than the consistent location of OL-UI lures. This suggests that landmark identity was highly relevant in the binding of features and induced biased response. In general, this main effect confirmed the hypothesis that OL-RI and NL-OI lures would lead to higher false alarm rates while NL-NI lures would lead to lower rates of false alarms. It also demonstrated that semantic information led to increased lure susceptibility. See Table 4 for false alarm means separated by lure type and see Figure 14 for a graph of false alarm rates.

The ANOVA also revealed an interaction between age and spatial organization, driving the interaction found in the d' analyses [$F(1, 58) = 6.25$, $p = .02$, $np^2 = .097$]. Similar to the d' analysis, this interaction demonstrates that older adults were not able to use spatial organization effectively to reject lures, see Figure 13. A paired samples t-test was computed to investigate the specific aging effects. False alarm rates were similar for older adults regardless of whether the grids were organized (*M* = .18) or unorganized (*M* = .15), *t*(29)=1.39, p = .18. Conversely, young adults effectively used spatial organization to reject lures (*M* =.09) and had more difficulty making accurate judgments when grids were unorganized (*M* =.13), *t*(29)=1.39, p = .18. There were two more two-way interactions; spatial organization and lure type [*F*(1, 58) = 3.65, *p* = .01, np^2= .059] as well as semantic association and lure type [*F*(1, 58) = 6.33, *p* <.001, np^2= .098]. However, these interactions can be better understood through the context of the three-way interaction of spatial organization, semantic association and lure type [*F*(1, 58) = 5.76, *p* = .001, np^2= .090].

To understand the variables driving these interactions we computed several paired samples t-tests. The effects of spatial organization on false alarm rates were examined by comparing trials in which grids were spatially organized to those in which grids were unorganized. The t-test revealed a significant difference between organized and unorganized study grids when the test grid contained a NL-OI lure [*t*(59)=-2.43, p = .02]. Organized grids led to decreased false alarm rates (*M* =.18), while unorganized grids led to higher false alarm rates (*M* =.27). When grids when organized, subjects were better able to reject new location lures, similar to the location false alarm data. When grids were unorganized, subjects over-relied on the landmark information, which was consistent with the studied grid, leading to increased false alarm rates. There was also a marginal difference for the OL-UI lure [*t*(59)=1.85, p = .07]. For this lure type, organized grids led to increased false alarm rates (*M* =.10) and unorganized grids had decreased false alarm rates (*M* =.05). In the context of OL-UI lures, subjects over-relied on location information when grids were organized to guide response since the landmark was not familiar. When grids were unorganized, subjects were not compelled to over-rely on location information since this information was not as distinct when unorganized.

Similar patterns emerged in the paired samples t-tests based on semantic association. Corresponding to the spatial comparisons, there was a significant difference between related and unrelated grids when accompanied with an OL-UI lure [$t(59)=-3.23$, $p = .002$]. When grids were related, subjects were less likely to false alarm ($M = .03$) than when grids were unrelated ($M = .11$). Similar to the identity false alarm data, when grids were related, participants could more readily reject an unrelated lure. However, when grids were unrelated, participants could no longer rely on semantic information and thus over-relied on spatial organization, complementing the spatial paired-samples t-test. The other significant difference revealed by the semantic association paired-samples t-test was found in the OL-RI lure [$t(59)=2.33$, $p = .023$]. In the context of this lure, related grids led to higher false alarm rates ($M = .24$) than unrelated grids ($M = .17$). For related trials, the landmark lure was related to all items on the previously studied grid. Similar to identity false alarm rates, a related lure on related trials was more difficult to reject than a related lure on unrelated trials. Thus, in combination trials, this landmark foil, combined with accurate location information, made it difficult for participants to reject this lure. Conversely, when grids were unrelated, participants did not over-rely on semantic information and could then more accurately reject the landmark lure as it was only related to one item on the previously presented grid. In general, on combination trials, there is no clear pattern as to what individual item feature played more of a role in accurately rejecting or false alarming to lures. False alarm rates were highly dependent on the type of grid presented and how this information was bound at test.

General Discussion

The current study compared the processes underlying online map processing and VSWM to understand how the two cognitive functions are related. It was predicted that these two functions would rely on the same cognitive processes. The role of location and identity information and how these two forms of information bind together were studied to determine which form of information was most salient in online map processing as compared to VSWM. Based on the prediction that map processing and VSWM share cognitive processes, it was expected that spatial organization would facilitate location memory, semantic association would facilitate landmark memory and that these two forms of information would positively interact. Lastly, the current study explored how these cognitive processes changed as a function of age. It was predicted that there would be a main effect of age, with older adults performing less accurately than young adults. It was also predicted that older adults would over-rely on semantic information of landmarks, while young adults would more likely use location information to guide response.

Effects of spatial organization. Spatial organization was expected to facilitate memory accuracy across all question types, particularly location questions. In terms of aging, it was predicted that older adults would not effectively use this information. Analyses confirmed that spatially organized maps specifically effected location question performance leading to high accuracy in recognition of previously studied maps. Spatial organization also led to increased accuracy on identity questions, although its effect was less pronounced than it was for location questions. Lastly, there was a main effect of spatial organization on combination questions, demonstrating that spatial organization was facilitative to binding.

This finding supports the theories proposed by Treisman and Gelade (1980), and Johnson and Pashler (1990) that spatial representations necessitate binding. Spatially organized grids allowed subjects to more readily remember location information and thus use this information more efficiently in binding. This finding also relates to the findings of Taylor et al (2014) who found in a similar task that attention to location information improved binding accuracy. Thus, directing subject’s attention to location information using clear spatial patterns or configurations led to more accurate binding. The overall effect of spatial organization parallels the VSWM work of Dai et al (2015) who found a similar overarching, positive effect of spatial organization on memory accuracy on individual item and binding questions. This corroboration of results demonstrates that both the traditional VSWM task and the map processing task relied on similar location processes.

There was also an interaction between age and spatial organization across all trials. For questions concerning memory for individual features, older adults were assisted by spatial organization whereas young adult accuracy did not rely as heavily on spatial organization, contrary to the original hypothesis. However, on combination trials, which necessitate binding, older adult performance was not affected by organization. Thus older adults were unable to appropriately use spatial organization on a more cognitively demanding task, requiring binding processes. This inability to effectively represent location information in a more cognitively demanding context confirms the hypothesis and supports research that proposed specific location processing deficits in VSWM and map processing due to aging (Kirasic, 1992; Lipman & Caplan, 1992; Wilkniss et al, 1997).

According to binding theories that propose location processing is an initial step in binding features, this interaction would explain the main effect of age on combination false alarm trials (Johnson and Pashler, 1990; Treisman & Gelade, 1980). Using this framework, it can be interpreted that older adults did not have accurate location representations and thus had difficulty binding location and identity information. However, this interaction, specific to combination trials, does not eliminate the possibility of a general age-related binding deficit, not specific to location processing. Hyun et al (2009) used both behavioral and neurological evidence to demonstrate that binding requires more cognitive resources, and would thus be a more difficult task. Several studies have proven that older adults have difficulty in this more cognitively demanding task (Chalfonte & Johnson, 1996; Meneghetti, 2011; Mitchell et al, 2000; Thomas et al, 2012a). Thus failure to accurately bind information may not have resulted from an initial deficit in location processing; rather, binding deficits could have resulted from the general cognitive demand of the task.

Effects of Semantic Association. It was predicted that semantic association would facilitate memory performance across all conditions, particularly identity questions. Furthermore, it was expected that older adult map memory would benefit from semantically related maps. The analyses revealed that semantic association did not greatly affect map memory in either age group, contrary to the hypothesis. Semantic association did play a large role in lure susceptibility on identity and combination trials. Subjects used semantic representations of associated study maps to guide response. This led to highly accurate response when lures were unrelated, as the lure item's semantic category was not a part of the representation. However biasing effects were induced when the lure item was related to the representation of the associated grid. In combination trials, identity lures led to stronger biases in response than location lures. This demonstrates an over-reliance on the mental representation of semantic category.

These representations are similar to categories discussed by Tversky (1992) in which it was proposed that representations of maps are based upon hierarchical semantic categories, rather than location information. While there were no main effects of semantic association to support this theory, semantic representations of maps was still influential in map memory. These results demonstrate a difference in VSWM and online map processing. In Dai et al (2015), there was a main effect of semantic association across location, identity and combination questions. Thus in a more traditional VSWM task, semantic association played a role in location memory.

The absence of this main effect in the current study, specifically the effect of semantic association on location memory, suggests that identity information may not be as salient in the map learning context, especially compared to location information.

Interaction of Spatial Organization and Semantic Association. It was predicted that the presence of both spatial organization and semantic association would lead to most accurate response, with a stronger effect in the young adult group. The observed interactions between these two factors demonstrate that the two forms of information were both important to online map processing. The interaction of spatial organization and semantic association led subjects to better encode and represent individual map features. When both organization and association were present on the study map, accuracy increased. Subjects were able to accurately encode representations of both the spatial layout of the map and its landmarks. The use of these holistic representations drove accurate top-down processing which led to appropriate response. Accuracy was also high when neither organization nor association was present. These high accuracy rates were attributed to accurate bottom-up perception, as subjects could not create a comprehensive representation of the map, spatially or semantically, and thus processed each landmark and accompanying location individually. However, when only one support was present, memory accuracy decreased. Subjects over-relied on their representation of one form of information, such as semantic category of the map, to guide response. Thus the interaction of spatial organization and semantic association led to changes in perceptual processes of the subjects, causing either highly accurate top-down or bottom-up processing, or biased top-down processing, depending on information available on the study map.

Combination trials revealed a similar pattern of accuracy to that of the interaction of spatial organization and semantic association on identity questions across age groups. This consistency demonstrates that the representations used to guide response on questions pertaining to individual features are transferred to the binding context. If a landmark from the previous study map was presented in a new location, the presence of spatial organization led to accurate response, as subjects did not solely rely on their representation of landmarks. If a location from the previous study map was presented with a new landmark, semantic association facilitated correct response, as subjects did not solely rely on their representation of the spatial configuration of the map. The analyses of combination lures demonstrated that in the absence of spatial organization, semantic association biased response, and in the absence of semantic association, spatial organization biased response, paralleling the interactions found in location and identity questions. Top down processes led to both accurate memory and biased responding, based on map resources available. These interaction results are similar to Dai et al (2015) who also found that the presence of both organization and association led to most accurate response.

Age also interacted with spatial organization and semantic association, revealing different processing strategies and abilities between young and older adults. On identity lure trials, older adult performance was not dependent on either semantic association or spatial organization, as opposed to young adults who were highly reliant on these forms of information. This stark difference in the use of map information between age groups illustrates that older adults were not able to effectively create or use comprehensive representations of the studied map based on spatial organization and semantic category.

This inability to accurately represent map information supports other studies that have found age-related deficits in map processing and VSWM (Chalfonte and Johnson, 1996; Kirasic, 1992; Lipman & Caplan, 1992; Wilkniss et al, 1997). However, several studies have found a more specific location processing deficit in older adults. In the context of remembering landmark information, both location and identity information were inadequately represented, suggesting that there are deficits in both forms of information processing, but perhaps to a lesser extent in semantic representations based on the observed location deficits.

VSWM and map processing. Spatial organization, as an individual feature had a positive effect on accuracy of response to location questions, binding questions, and to a smaller degree identity questions. Conversely, semantic association, as an individual feature solely played a role in landmark identity trials in young adults. Furthermore, the interaction of spatial organization and semantic association affected encoding of individual features and binding of features and representations of one form of information could lead to biased response. Spatial organization led to overall better performance across question type, suggesting it involves less effortful encoding and plays a role in binding features. Semantic association biased memory of grids, demonstrating that some map information is stored as hierarchical categories. The interaction of spatial organization and semantic association led to highly accurate map representations when both were present. However, if only one support was present, representations of this support led to biased responding. In the absence of organization and association, effective bottom-up processing was induced.

The way these forms of information were processed did not remain the same between age groups. While general aging deficits were found, a more specific deficit was found in the ability to appropriately use spatial organization to guide response. Effects of age across all trials demonstrated a general age-related deficit on the task, consistent with Meneghetti et al (2011) and a specific deficit in location processing, supporting previous research on VSWM and map processing in older populations (Dai et al, 2015; Wilkniss et al, 1997). Analyses also indicated an inability to appropriately integrate location and identity information, which is necessary for online map processing. These findings reveal the similar cognitive underpinnings that drive accurate VSWM and map processing through the context of aging, specifically in deficits in the ability to represent location information and integrate it with identity information.

These results are consistent with both VSWM and map processing literature. Garden, Cornoldi and Logie (2002) found that location and identity information interacted to bind map landmarks to their specified locations in a map learning task that used a VSWM paradigm. Meneghetti et al (2011), Kirasic (1992) and Lipman and Caplan (1992) found specific VSWM and location memory deficits in older populations. These deficits were also observed in a map learning task (Wilkniss et al, 1997). The current study supports previous research concerning characteristics of processes involved in VSWM and map processing, particularly less effortful location processing, the importance of location processing on binding, and age-related deficits in these tasks. More importantly, this study advances the understanding of these cognitive functions by demonstrating that they transfer to the map processing context. In using a VSWM paradigm to study processes underlying online map processing, it was found that VSWM and map processing share cognitive mechanisms that change as a function of age. Ultimately, the processes required to represent VS information and perform online map processing are shared and differ only in a matter of degree.

Questions for future research. This study serves as an initial step in understanding the relationship between these two cognitive functions. There are several questions the current study could not answer but future research may wish to address. First, future research should consider how to appropriately test VSWM and map processing using more realistic maps. The maps created for the current study were similar to grids presented in a more traditional VSWM task. Thus in order to continue research in the overlap of VSWM and online map processing, it is important to ensure that study materials are more similar to maps people would use on their phone or on the computer as they navigate the world. Furthermore, maps such as Google Maps use symbols of landmarks next to the linguistic label of landmark. While maps are generally linguistically-based, we wonder whether subjects, particularly older adults, would rely more on landmark information if the landmark identities contained accompanying symbols, similar to Thomas et al (2012a) or objects in Dai et al (2015). Future research should examine how the addition of symbols to the paradigm changes the extent to which people, especially older adults, process and rely on location information presented on maps. Adding symbols to this paradigm may also make the stimuli more representatives of maps used by the general population. Lastly, future research should explore how effects of age vary due to presentation time of stimuli. Perhaps, similar to the design of Thomas et al (2012a), older adult performance would have been closer to that of young adults if the older age group was given more study time. Increased study time has been proven to improve working memory performance in older adults, as they need more processing time on tasks (Salthouse, 1994). Increased study time could provide more insight as to what types of information older adults rely on when given more time to scan maps. However, by keeping study time the same across age groups in the current study, we were able to see general VSWM processing differences that emerge with age.

Conclusion

The current study takes an important first step in applying and integrating well-established knowledge to a domain in which much exploration is needed. This investigation compared underlying processes used in VSWM and online map processing. It was found that there is much overlap between the two processes particularly in the processing of individual featural information and age-related changes. However one key difference found was the extent to which subjects relied on location information. This reliance implies that map processing depends more upon the processing of location information, based on higher accuracy on spatially organized maps across age groups. In reference to binding, which involves the manipulation of more complex information, it was found that spatially organized information improved binding ability and memory in young adults. These findings suggest that spatial organization relieved some of the cognitive demand of binding. This is important because it provides evidence that binding is facilitated by the processing of location information and thus does not rely on all featural information equally. Furthermore, older adults' inability to use spatial organization to bind information demonstrates an inability to appropriately use location information to ease cognitive load. This investigation of binding mechanisms and associated age-related changes adds to both VSWM and map processing literature in demonstrating the importance of location processing in binding ability and accuracy.

This study has important implications for understanding how we interpret maps rapidly and effectively. Due to widespread accessibility to computers and smartphones, we always have maps available to us, and we constantly switch between looking at maps and navigating the environment that the map represents. The current study provides new insight as to what processes are employed by our cognitive systems to appropriately handle these situations. The current study adds to and integrates the existing literature on VSWM and map processing in order to gain a deeper understanding of the processes employed that allow us to efficiently and successfully apply map information to the physical environment.

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Table 1
Means of Location Trials in Younger and Older Age Groups

	Younger				Older			
Type of Data	OR	OU	UR	UU	OR	OU	UR	UU
Hits	0.867	0.950	0.633	0.667	0.883	0.917	0.550	0.617
False Alarms	0.067	0.072	0.187	0.203	0.133	0.110	0.257	0.350
d'	3.925	4.376	2.026	2.194	3.667	4.021	1.324	1.213

Table 2
Means of Identity Trials in Younger and Older Age Groups

	Younger				Older			
Type of Data	OR	OU	UR	UU	OR	OU	UR	UU
Hits	0.900	0.833	0.800	0.883	0.900	0.783	0.733	0.700
False Alarm-Related	0.167	0.317	0.417	0.133	.383	0.200	0.428	0.261
False Alarm-Unrelated	0.017	0.250	0.144	0.111	.083	0.178	0.144	0.150
d'	3.980	2.670	2.467	3.656	3.189	2.877	2.075	2.281

Table 3
Means of Combination Trials in Younger and Older Groups

	Younger				Older			
Type of Data	OR	OU	UR	UU	OR	OU	UR	UU
Hits	0.800	0.811	0.700	0.722	0.800	0.756	0.733	0.722
False Alarms-collapsed	0.082	0.100	0.119	0.141	0.203	0.152	0.135	0.162
d'	3.361	3.027	2.556	2.492	2.390	2.581	2.605	2.421

Table 4.
Means of Combination False Alarm Trials in Younger and Older Groups

	Younger					Older				
Lure Type	OR	OU	UR	UU	Average	OR	OU	UR	UU	Average
NL-OI	0.133	0.117	0.183	0.333	.192	0.317	0.167	0.217	0.350	.263
NL-NI	0.033	0.025	0.050	0.025	.033	0.058	0.033	0.033	0.042	.041
OL-RI	0.133	0.15	0.200	0.150	.158	0.383	0.183	0.250	0.183	.250

OL-UI	0.017	0.100	0.033	0.050	.050	0.050	0.217	0.033	0.067	.092

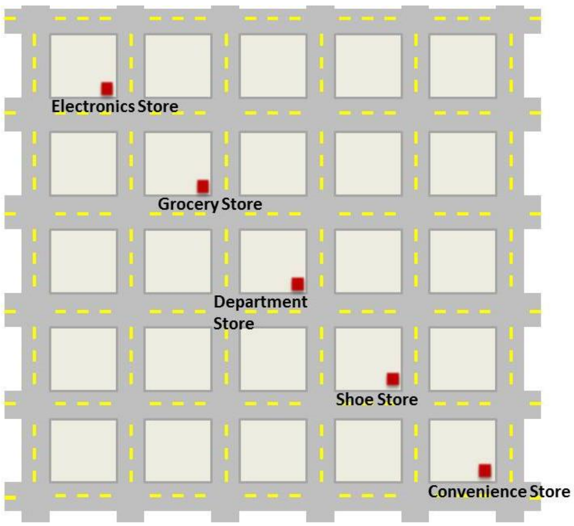

Figure 1. Organized Related Study Grid. Study grid for sample test grids in Figures 5-11.

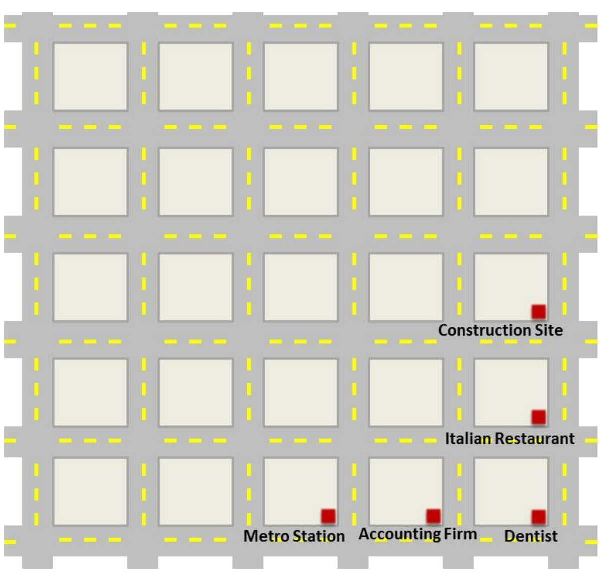

Figure 2. Organized Unrelated Study Grid

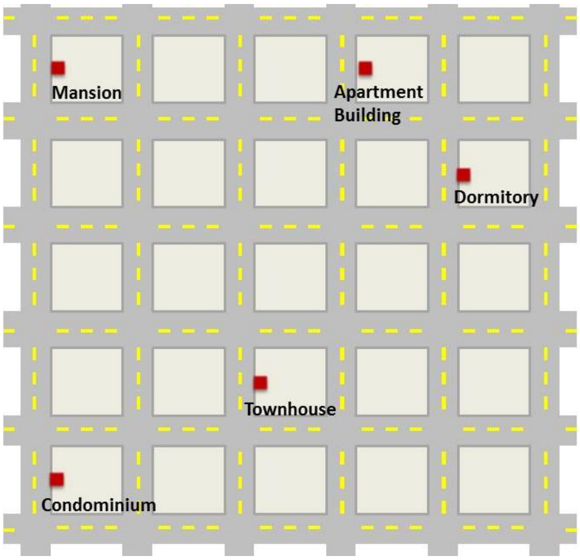

Figure 3. Unorganized Related Study Grid

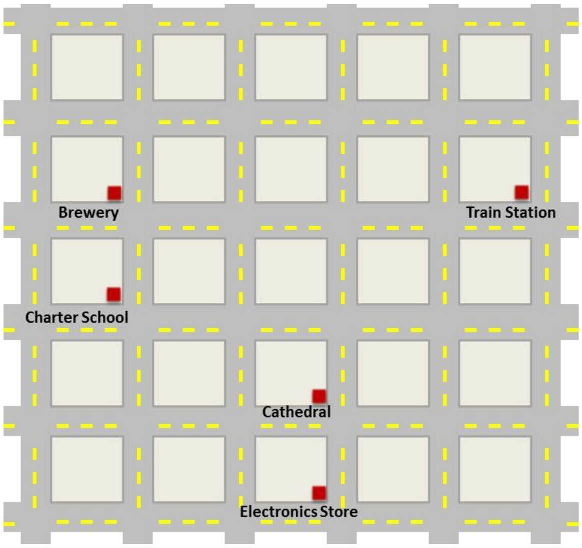

Figure 4. Unorganized Unrelated Study Grid

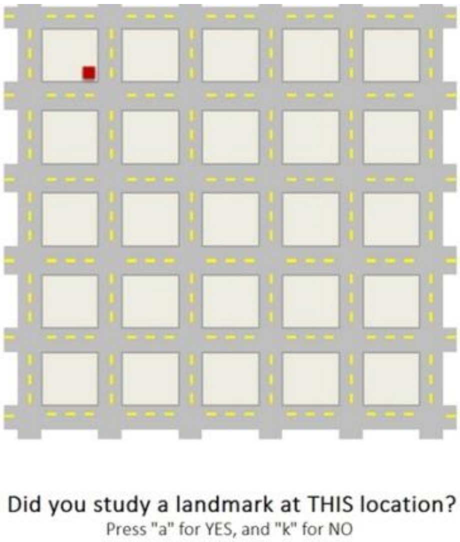

Figure 5. Location Test Grid

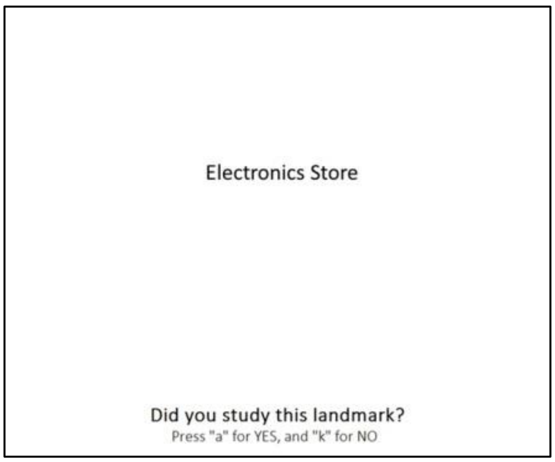

Figure 6. Identity Test Grid

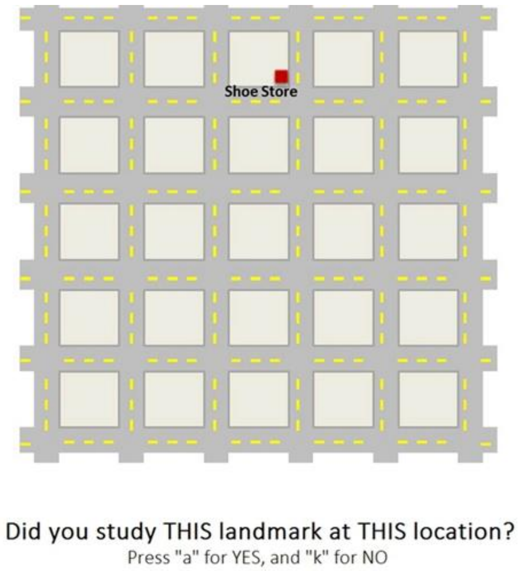

Figure 7. New Location- Old Identity (NL-OI) lure

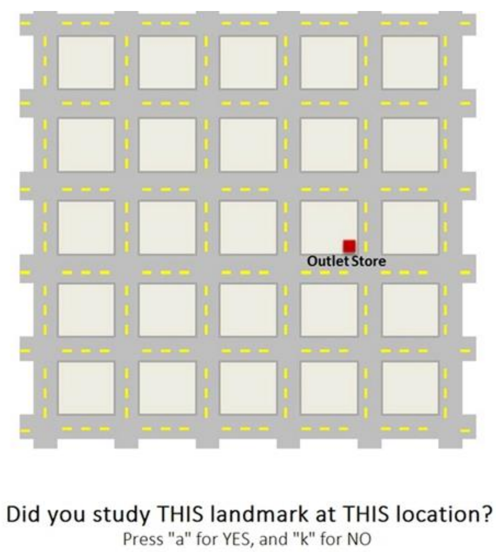

Figure 8. New Location- Related Identity (NL-RI) lure.

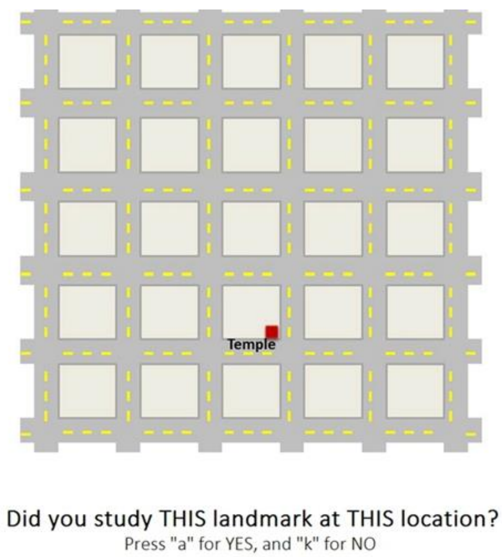

Figure 9. New Location, Unrelated Identity (NL-UI) lure

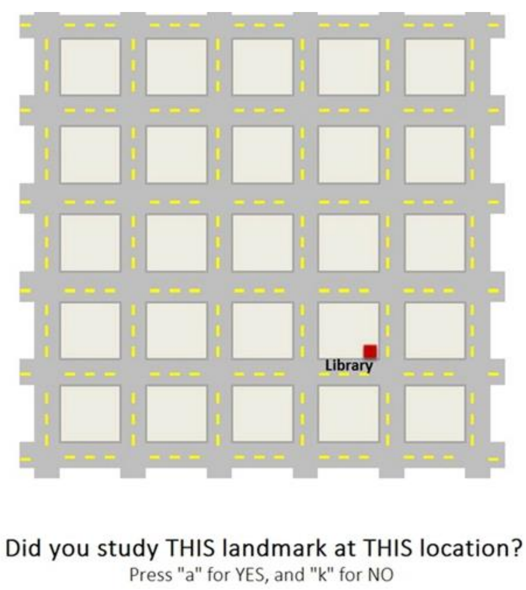

Figure 10. Old Location Unrelated Identity (OL-UI) lure.

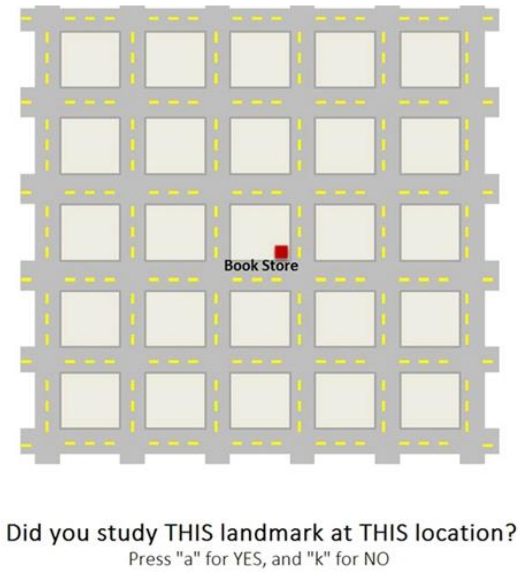

Figure 11. Old Location Related Identity (OL-RI) lure.

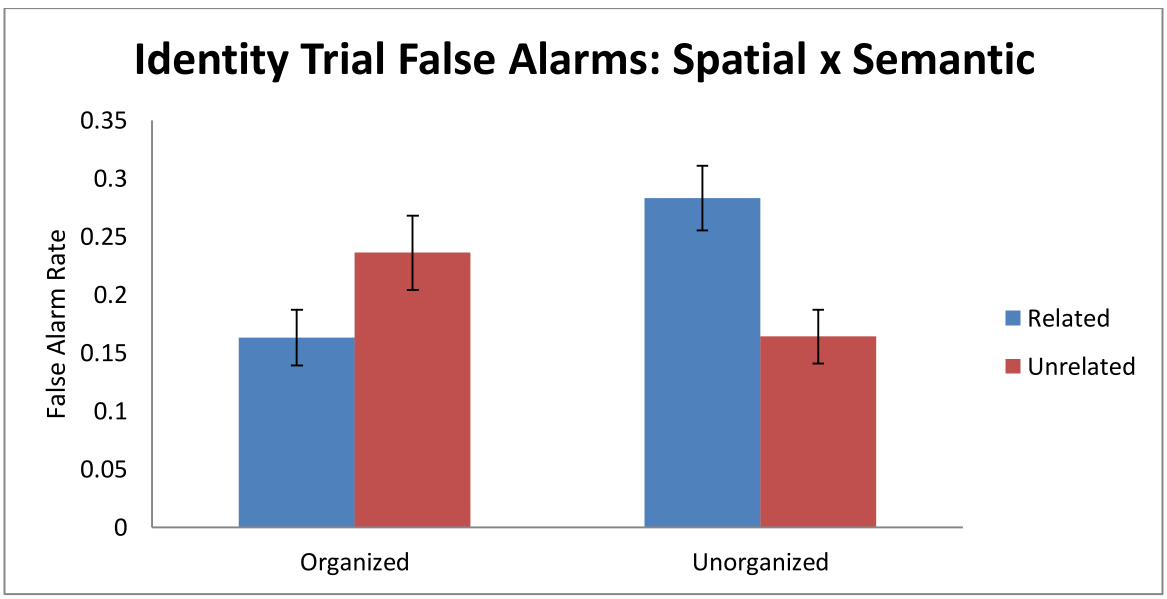

Figure 12. False alarm rates on object lure trials. Error bars represent the standard error. Organized and related grids and unorganized and unrelated grids led to accurate rejection of lures. Organized, unrelated grids and unorganized, related grids induced biased responding and thus higher false alarm rates.

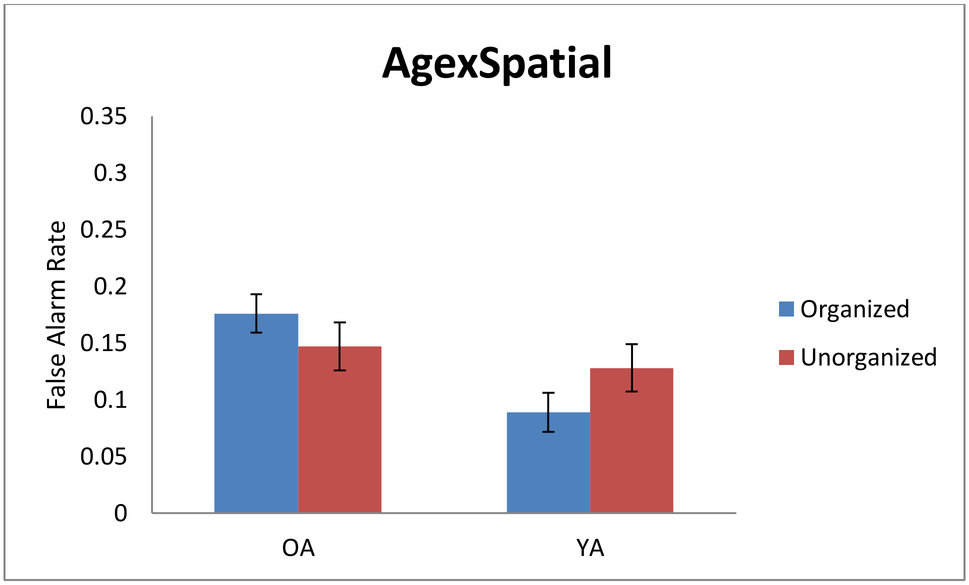

Figure 13. False alarm analyses for combination questions. Error bars represent the standard error. Older adults were less able to use spatial information to guide accurate response. Young adults relied on spatial organization to increase memory accuracy.

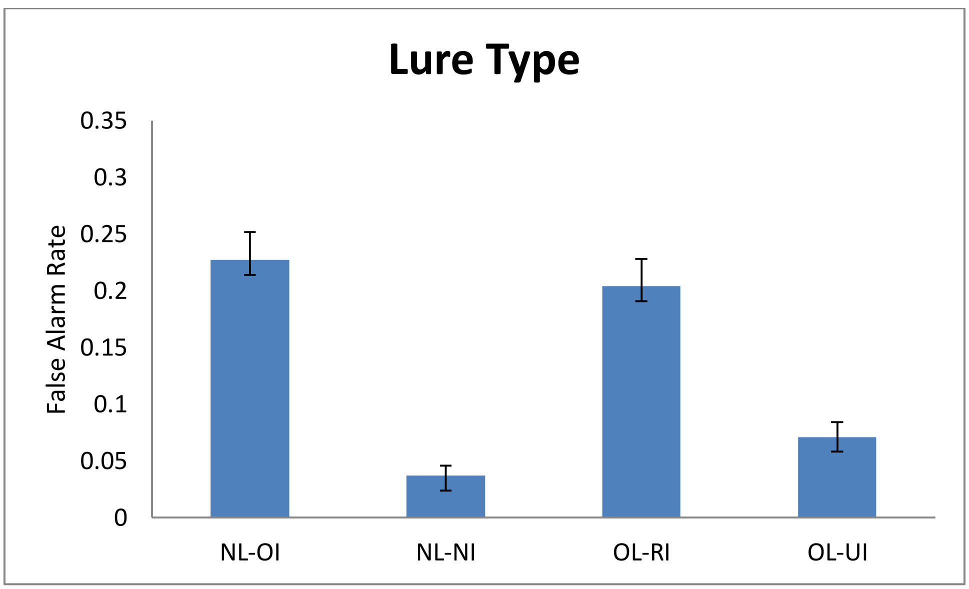

Figure 14. False alarm rates on combination questions separated by lure type. Error bars represent the standard error. NL-OI and OL-RI lures led to highest false alarm rates as they were

most similar to previously studied grid information. The differences between each lure type were significant except between NL-OI and OL-RI lures.

Appendix

Table 5
Semantic Categories and Associated Landmarks

Categories	Landmarks
Stores	Grocery
	Department Store
	Electronics
	Hardware Store
	Outlet/Discount Store
	Convenience Store
	Book Store
	Shoe Store
Educational Institutions	Private College
	Public University
	Elementary School
	Middle School
	High School
	Charter School
	Community College
	Preschool
Religious Institutions	Church
	Mosque
	Temple
	Cathedral
	Synagogue
	Monastery
	Abbey
	Chapel
Public Services	Fire Station
	Police Station
	Library
	Court House
	Post Office
	Water Department
	City Hall
	Waste Management
Health Care Services	Hospital/Emergency Room
	General practitioner

	Walk-in Clinic
	Mental hospital
	Dentist
	Physical therapy
	Eye doctor
	Chiropractor
Sports Venues	Football stadium
	Baseball field
	Basketball court
	Ice rink
	Tennis court
	soccer field
	Swimming Pool
	Running track
Restaurants	Diner
	Fast food
	Seafood restaurant
	Pizza parlor
	Bistro
	Steakhouse
	Chinese restaurant
	Italian restaurant
Entertainment	Casino
	Movie theater
	Night club
	Bowling alley
	Museum
	Art gallery
	Pool hall
	Live theater
Outdoor Venues	Park
	Amphitheater
	Zoo
	Playground
	Farmer's market
	Public gardens
	Monument
	Sculpture Park
Businesses	Law firm
	Bank
	Accounting firm
	Realtor
	Trade center

	Hotel
	Advertising and marketing firm
	Convention center
Residential Buildings	Single family home
	Public housing complex
	Mansion
	Dormitory
	Townhouse
	Apartment building
	Multi-family/triple decker
	Condominium
Transportation	Airport
	Bus station
	Metro station
	Train station
	Taxi stop
	Parking garage
	Bike stand
	Helipad
Industrial	Brewery
	Factory
	Power plant
	Refinery
	Mill
	Packaging Plant
	Warehouse
	Construction site