Effects of Global and Local Processing on Visuospatial Working Memory

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Abstract. If you want to find something, you need to know what you are looking for and where it was last located. Successful visuospatial working memory (VSWM) requires that a stimulus identity be combined with information about its location. How identity and location information interact during binding presents an interesting question because of 1) asymmetries in cognitive demands required by location and identity processing and 2) the fact that the two types of information are processed in different neural streams. The current studies explore how global and local processing approaches impact binding in VSWM. Experiment 1 explores effects of global spatial organization. Experiment 2 induces local processing demands through memory updating. Results show better location memory with both global and local processing, but also suggest that the processing focus (global or local) affects the interaction of location and identity processing in VSWM.

Keywords: visuospatial working memory, location-identity binding, configural processing, memory updating, local/global processing.

1 Introduction

You have recently moved to a new town and feel you have a basic idea of local businesses locations. When you do misremember, you notice two different problems. In one case, you remember, for example, that there was a business on the south end of Barrett Rd., but cannot remember what type. In other words, you remembered a location, but cannot remember the business identity (identity memory failure). In the other case, you remember having seen a Thai restaurant, but cannot remember where (location memory failure). Both errors represent a failure to bind identity and location information. What might affect the likelihood of these error types? In line with this example, the present work explores how factors contributing to global versus local processing affect visuospatial working memory (VSWM), including location memory, identity memory, and location-identity binding.

1.1 Visuospatial Working Memory

VSWM involves memory for object identity, location and their combination (binding). Identity memory first relies on object recognition, a ventral stream process [1, 2]. Location can be coded on either a fine-grained, individual basis, giving exact position and/or at a categorical level, designating position relative to a larger context and thus offering a more global sense of position [e.g., 3, 4, 5]. Location memory involves the "where" or dorsal stream [2], although some research also suggests a role for ventral areas [1]. Although identity and location processing alone are important in establishing memory representations, binding the two is crucial for successful VSWM. Through binding, identity and location become integrated and represented as a single unit [6].

How identity and location information interact during binding presents an interesting question for a number of reasons. Identity and location processing involve different neural circuits. As discussed above, location processing engages the ventral stream and identity processing the dorsal stream. Additionally, attentional demands for processing these two information types may differ. Some researchers have argued that location processing is automatic [7]. However, because factors such as practice, intention to learn, strategic processing, and age influence spatial memory, automaticity has been called into question [8, 9]. Our earlier work [10] suggests less effortful, or partially automatic [11], processing of location information.

The role of identity memory in VSWM has received much less attention. Taken alone identity memory has similar characteristics to verbal working memory (VWM), particularly for name-able or verbally processed items [12]. An important point for the current work emerging from the VWM literature is that maintenance of information is effortful. Recent debates on working memory capacity suggest a low capacity of 4 items without strategic processing or rehearsal [13, 14] and the classic 7 plus or minus 2 items with rehearsal or strategic processing [15].

When considering VSWM components, asymmetries emerge. Notably, research suggests that position processing proceeds with limited effort [10, 16], whereas identity processing ("what") requires central effort [16, 17]. This asymmetry has implications for identity-location binding. The reduced effort of location processing should give it precedence in memory. However, characteristics of the information being processed as well as processing goals may shift around the weighting of the VSWM components. The present work explores stimulus characteristics that encourage global processing (Experiment 1) and task goals requiring local processing (Experiment 2) and their effects on VSWM.

1.2 Local Versus Global Processing

Visual scenes and individual stimuli involve details that form a whole when related together. In processing this information, one can focus on the details (local processing) or on how the details fit together (global processing). Navon [18] proposed a *global dominance hypothesis* or *global precedence*, with faster processing and reduced interference for a global interpretation of his letter stimuli. More recently, Förster and colleagues [19, 20] suggest malleability in global and local processing. In Förster's $GLOMO^{sys}$ model, he suggests that real-world factors (e.g., arousal; [21]) affect global versus local perceptual and conceptual processing and that the processing approach can carry over across tasks and modalities. Förster [22] suggests that global or local processing should be conceptualized as a cognitive approach, i.e. a content-free way of perceiving the world that can be applied across perceptual and conceptual modalities.

In terms of a cognitive approach, why would global processing be dominant? One answer emerges from the cognitive literature. Global precedence emerges across cognitive processes to help us to manage information overload. For example, we tend to generalize instances into categories based on commonalities and use those categories to interpret new instances. In other words, global processing organizes information into manageable and informative units.

Viewed this way, VSWM, and its components, should show global precedence. There is some indication that location memory does. Spatial correspondence studies suggest that people consider individual locations within an organized structure (see [23] for a review). Similarly, when locations can be grouped into spatial categories, memory appears biased toward the spatial category as evidenced by under-estimation of distances within a category and over-estimation across categories [e.g., 24, 25, 26]. Further, configural changes disrupt location processing in VSWM [27]. Global/relational processing via semantic categories suggests that the identity aspect of VSWM also shows global precedence. Evidence of category use shows lower accuracy and longer reaction time for within- compared to across-category responses [28]. Further, when individual items all relate to a single strong associate, that associate is remembered as having been presented when it was not [false memory; 29] and is remembered at an even higher rate when it was presented [30]. However, global precedence can only emerge in VSWM if the information being processed can be conceived as having hierarchical structure. For location information, items forming some kind of configuration would accomplish this; for identities, different semantic categories would need to be distinguished.

Individual differences may guide tendencies to process locally or globally. Global precedence appears to increase with age. With spatial arrays, children seem to individuate elements, although they will use a meaningful organization [23, 31]. Adults readily extract and advantageously use perceptual and conceptual organizing information [29, 32]. Older adults tend to over-rely on semantic organizing information, which can, in some cases, increase false memory [33]. Habitual processing approaches also play a role. With environment learning, Pazzaglia and De Beni [34] find individual differences in habitual spatial processing that map onto local versus global processing. They identify three spatial processing styles for environments, *landmark, route,* and *survey*. *Landmark* processing has the most local focus while *survey* processing takes the most global, configural approach.

1.3 Previous Work

Our previous work [10] explored VSWM, separating location, identity, and binding of the two. Participants studied 5x5 grids containing between 2 to 5 shapes. Immediately after test, they made a Judgment of Learning (JOL) and then completed one of three *yes/no* recognition test trials (assessing identity, location, or both identity and location). In Experiment 1, participants knew whether they would be tested on location, identity, or both, so could separate them and strategically encode. In Experiment 2, the test type could not be predicted, so separation of the elements only occurred at retrieval.

The results provided insights into VSWM. First, cognitive load, as operationalized by the number of objects in the array, differentially affected the memory types. Identity memory accuracy decreased as load increased, as did combined object/identity memory. Location memory accuracy, in contrast, decreased from 2 to 3 objects, but then remained relatively stable. We interpreted the lack of sensitivity to array size as indicating that learning location information was less cognitively demanding than identity or combination information. Alternatively, it could suggest that location information is processed first, as differences between location and identity memory were more pronounced when participants had less time to study the array ([10] Experiment 1b).

The lack of sensitivity to array size for location information had one interesting exception [10]. Location accuracy decreased from 2 to 3 objects, but then remained stable. The decrease from 2 to 3 objects likely reflects cognitive load. What might explain the stability with 3 or more objects? Three or more objects form a configuration; two objects only ever form a line. Thus, with 3 or more objects, participants may adopt global, configural processing to strategically remember locations. This may be akin to global precedence [18], showing configural processing when possible. The first study in the present work will further explore configural processing in VSWM.

2 Experiment 1: Location-Identity Binding with Spatial Organization

Within VSWM, location processing appears to be less cognitively demanding than identity processing. When items in a spatial array can be processed configurally, array size has a negligible effect on location memory [10]. Spatial configural processing occurs even when the objects do not form identifiable configurations

[25]. In our earlier work, we randomly located objects within a 5x5 grid. Experiment 1 makes configural processing more obvious by using easily identifiable configurations. The study compares VSWM components with 2-object arrays, which do not form a configuration, to 5-object arrays with either a recognizable configuration (organized) or an emergent one based on random object placement (unorganized). We predict that the affordance for location processing provided by the organized configuration will aid location memory and also negatively impact identity memory. The spatial configuration chunks location memory, improving memory for those locations. However, a good Gestalt form appears to impair visual target detection [35], suggesting that the global configuration draws attention from local object processing. This prediction is also consistent with more general models of comprehension [36].

2.1 Method

Participants. Eighteen Tufts undergraduates (aged 18 to 24) participated in exchange for partial course credit.

Design. The experiment used a 3(Array Type: *2-object, 5-object Unorganized, 5-object Organized*) X 3(Question Type: *Identity, Location, Combination*) within-participant design.

Materials. Stimuli consisted of 5 x 5 grids containing either two or five objects. Objects consisted of twenty simple shapes. When the grid contained 5 objects, they were arranged in either an organized manner (i.e., analogous to the construction of Navon [18] figures) with objects placed in adjacent grid cells and together forming a larger recognizable shape such as an L, square, V, or T or in an unorganized manner (i.e., random placement with no consistently recognized structure). See Fig. 1 for sample grids. A total of 108 grids were used, 36 of each of the three types. Across trials, both the object shown and location it occupied on the grid were relatively equally balanced.

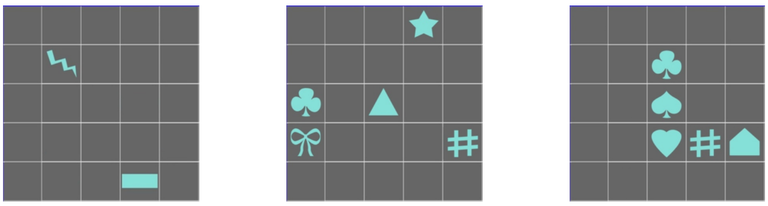

Fig. 1. Example of a 2-object, a 5-object unorganized, and a 5-object organized grid.

Procedure. The Tufts University Social, Educational and Behavioral Research (SBER) IRB approved all procedures. Experiment instructions informed participants that they would "be presented with a series of displays containing various shapes in various locations within a grid." The experiment was presented on an Apple™ computer running SuperLab (version 4.0; Cedrus Corporation). At the beginning of each block, participants were told to attend either to object shapes, locations, or both shapes and locations for a later test. Following instructions, participants completed three practice trials (one from each question type – identity, location, and combined identity and location).

Experimental trials consisted of a 3-part procedure involving studying a grid, then rating their learning of the grid, and finally completing a *yes-no* recognition question. Each trial began with a 500ms central fixation cross, followed by a study grid for 1500ms. A mask and a central fixation cross then replaced the grid for 500ms. Participants then provided a Judgment of Learning (JOL) regarding the likelihood they would be able to recognize, depending on block, either object identity, location, or identity and location. Participants recorded JOLs using a Likert scale ranging from 0 (*not likely at all to recognize*) to 9 (*extremely likely to recognize*). Finally, participants responded to the grid's corresponding *yes-no* forced choice recognition probe (which assessed either identity, location, or both) by pressing either the yes ("c") or no ("m") key.

Recognition probes had 1/3 of the questions paired with previously presented stimuli (correct) and 2/3 of the questions were paired with stimuli not previously presented (incorrect lures). This ratio was used to provide a greater proportion of incorrect lure trials for analysis without also engendering a response bias. The 36 object-identity questions presented a single object and asked, "Was this shape presented in the previous grid?" The 36 location questions presented a blank grid with one square shaded red and asked, "Was an object presented in this location in the previous grid?" Finally, the 36 combination identity-location questions presented a single object within a grid and asked, "Was this shape presented in this location in the previous grid?" With our design, participants could commit only one type of error on identity or the location trials (correct recognition or not), but could commit one of three types of errors when recalling combined identity-location information. Specifically, they could recall a new (incorrect) identity in an old (correct) location, an old (correct) identity in a new (incorrect) location, and finally, a new (incorrect) identity in a new (incorrect) location. At the end of the experiment, participants filled out a general demographic questionnaire.

2.2 Results

With the present paper's focus on VSWM, we present only the memory, and not the metacognitive data here. All p-values reported were less than 0.05 unless otherwise stated. Recognition hits and false alarms were examined separately. To begin, we compared memory for location and identity to examine how spatial organization affected memory for each VSWM element. A 3(Array Type: 2-object, 5-object organized, 5-object unorganized) X 2(Element: Identity, Location) within-subjects ANOVA performed on hit proportions found a main effect of Array Type, $F(2, 34) = 31.06$, $\eta_p^2 = .65$. In addition, the interaction between Array Type and Element was significant, F(2, 34) = 8.09, η_p^2 = .32. Memory for location was better than memory for identity with spatially organized grids, t(17) = 3.23, d = 1.16 (See Fig. 2). There were no other significant differences between location and identity memory.

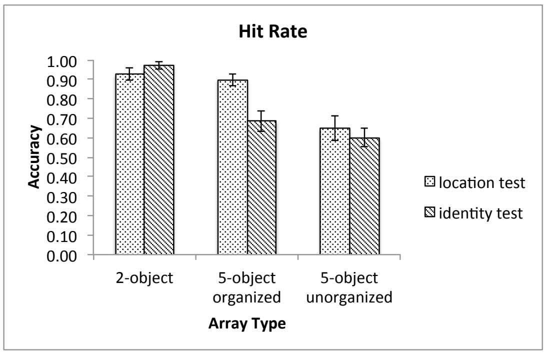

Fig. 2. Experiment 1 hit rate showing better location memory for organized grids.

A similar analysis on false alarm proportions also yielded a main effect of Array Type, F(2, 34) = 28.53, η_p^2 = .63, and an interaction between Array Type and Element, F(2, 34) = 16.98, η_p^2 = .50. As Fig. 3 illustrates, participants more often false alarmed to location than identity lures when arrays consisted of two objects. This difference was marginally significant after Bonferroni correction, t(17) = 2.30, p = .04. In contrast, participants false alarmed more often to identity lures as compared to location lures with 5-oject organized arrays, t(17) = 4.55, d = 1.57. False alarm responding did not differ when arrays were unorganized.

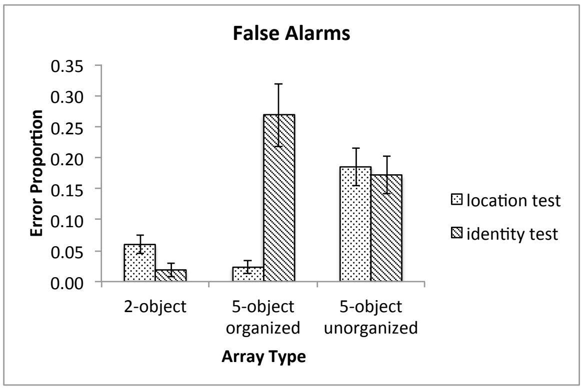

Fig. 3. False alarm rate showing high identity false alarms for organized grids.

With combination trials, analyzed separately, we examined how spatial organization affected identity-location binding. As with the previous analysis, hits and false alarms were analyzed separately. For hit proportions, we found an effect of Array Type, F(2, 34) = 28.69, η_p^2 = .63. Hit proportions were highest when participants studied 2-object grids (M = .89). There was a dramatic hit-rate drop with 5-object organized (M = .57) and 5-object unorganized (M = .44) grids. Planned comparisons revealed differences between 2-object and 5-object organized arrays, t(17) = 4.57, d = 1.41, and between 2-object and 5-object unorganized arrays, t(17) = 10.32, d = 2.78. The difference between organized and unorganized arrays did not reach significance.

Memory integration is best understood by examining false alarms. In this study we constructed lures to include studied objects presented in unstudied locations, and unstudied objects presented in studied locations. These two lure conditions were particularly important in assessing identity and location binding. A third lure condition presented unstudied objects in unstudied locations. A 3(Array Type: 2-object, 5-object organized, 5-object unorganized) X 3(Lure Type: New Object/Old Location, Old Object/New Location, New/New) within-subjects ANOVA found main effects of Array Type, F(2, 34) = 12.28, η_p^2 = .42, and Lure Type, F(2, 34) = 5.06, η_p^2 = .23. False alarms were lowest for the smallest array size and were lowest with New/New lures (see Fig. 4). More importantly, we found an interaction between Array Type and Lure Type, F(4, 68) = 3.81, η_p^2 = .18. As we were particularly interested in memory integration, we conducted a follow-up 3(Array Type: 2-object, 5-object organized, 5-object unorganized) X 2(Lure Type: New Object/Old Location, Old Object/New Location) ANOVA. Again, the interaction between Array Type and Lure Type was significant, F(2, 34) = 4.62, η_p^2 = .21. Planned comparisons revealed that when participants studied 5-object organized grids, they had more difficulty rejecting an unstudied object in a studied location (M = .31) as compared to a studied object in an unstudied location (M = .11), t(17) = 2.43, d = .89.

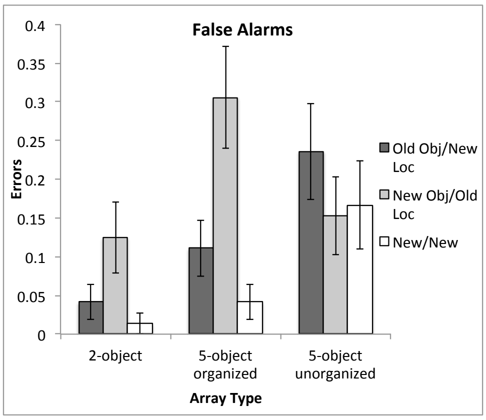

Fig. 4. Experiment 1 false alarm rates to different lure types with combination location-identity memory.

2.3 Discussion

We found that spatial organization impacted VSWM, such that when presented with spatially organized grids participants were better able to recognize previously presented location, rejecting location lures. This was particularly pronounced on combination trials in which participants had to remember both location and identity information. Under these conditions, participants made significantly more errors remembering object identity as opposed to location. These data suggest a prioritization of location information over identity information. Whether this priority involves less effortful or earlier processing of location information remains an open question.

The false-alarm results provided the most insight into how spatial organization affected location-identity binding. Notable in these results is that participants false-alarmed to identity information at a much higher rate with 5-object organized than with 5-object unorganized grids. With 5-object unorganized grids, they false-alarmed roughly equivalently to location and identity information. This is consistent with false alarm pattern for 5-object arrays in other, unpublished data from our labs [37]. Thus, spatial organization increases processing of location information in VSWM to the detriment of identity information.

Would identity processing be enhanced if it had a global structure and location did not? Current work in our labs is addressing this question, using a similar paradigm. In this new work, global structure for identity is defined through semantic categories. It pits a global focus for location against one for identity by presenting either semantically related or unrelated objects in either spatially organized or unorganized grids. Alternatively, would identity processing be enhanced with a greater local focus? Experiment 2 addresses this question.

3 Experiment 2: Location-Identity Binding with Local Focus through Updating

Experiment 1 suggests that when object locations form an interpretable global configuration, location processing appears to be enhanced at the expense of identity. Experiment 2 invokes local processing to examine its effects on VSWM. To do so, we used an updating paradigm modeled after Artuso and Palladino [38]. In this paradigm, participants update memory of a single array object (either object identity, location, or both). With this design, we can compare a local focus on individual component parts of VSWM and to a focus on their combination. We predict that a local focus will enhance processing on the focused information. To limit configural processing, here we use 3x3 grids with 3 objects.

3.1 Method

Participants. Thirty-four Tufts University undergraduates, ranging in age from 18 to 23, participated in exchange for monetary compensation.

Design. The experiment design involved a 2(Semantic Relatedness: related, unrelated) x 4(Updating Type: Identity, Location, Combination, Nothing) x 2(Test Type: Identity, Location) mixed-factor design. Semantic relatedness served as a between-participant factor and Updated Information and Test Type served as within-participant factors.

Materials.

Study Materials. The stimuli consisted of 432 3x3 grids containing three object pictures, drawn from Snodgrass and Vanderwart [39]. We used 70 pictures, 10 each from 7 semantic categories: animals, tools, clothes, transportation, fruit, furniture, and body parts. In half of the grids, objects were semantically related and in the other half they were unrelated. Pictures placement in grids was random, but followed overall constraints, including 1) using each object and grid location relatively equally (20 to 25 times) across the stimuli and 2) any two objects or any two locations could not be used within the same grid more than 5 times.

Each study grid had associated updating grids, which related to the study grid in one of four ways. For an identity update, one of the object identities changed. If a semantically related grid, the new identity belonged to the same semantic category (e.g., if the study grid had a *cat, tiger, dog*, the identity change grid might have *cat, elephant, dog*). For semantically unrelated grids, the new object belonged to a different semantic category than the replaced object (e.g. if they studied *cat, arm, banana*, the updated grid might have *cat, arm, dress*). For a location update, object identities remained constant, but one object changed location, appearing in one of the six open locations. For a combination update, both an object identity and its location changed. The identity change depended on whether the objects were semantically related, as described above. Finally, for "nothing" updates, the grid was identical to the study grid.

Test Materials. The experiment involved location and identity tests. *Identity tests* used the object pictures, presented individually. For a given trial, the picture either corresponded to one in the most recently studied (updated) grid (*old*), had occurred in the first-studied, but not in the updated grid (*intrusion*) or was not studied in the trial (*new*). New items matched the semantic category for semantically organized grids and came from a different category for semantically unrelated grids. *Location tests* involved a 3x3 grid with one of the squares colored red. As with the pictures for the identity test, the designated location was either one most recently studied (*old*), had been originally studied, but then updated (*intrusion*), or was an unstudied location (*new*). For both test types, 50% test items were old, requiring a *yes* response and the other 50% required a *no* response (equally divided between intrusion and new information).

Procedure. Tufts University SBER IRB approved all procedures. Participants were randomly assigned to study semantically related or semantically unrelated grids. To start, participants read instructions about the experimental procedures, presented on the computer screen. The experiment was presented on an Apple™ computer running SuperLab (version 4.0, Cedrus Corporation).

Each trial involved a self-paced sequence of grid study, grid updating, and immediate forced recognition test. The sequence unfolded as follows. For grid study, a grid appeared on the screen. The participant studied and then hit the space bar to proceed. Average study time was 3.30 seconds. Next a single dot appeared in the center of the screen. Average "remember" time was 3.30 seconds. The dot signalled participants to imagine the grid they had just studied. When finished imagining, they pressed the space bar to continue. Next came the updating phase. Participants viewed one of the associated grids that was either the same as in the study phase (nothing updated) or had been changed in one of three ways (identity, location, combination). Then the single dot again appeared, signalling the participant to imagine the updated grid (or the same grid if nothing had changed). Average "remember" time was 5.70 seconds. After pressing the space bar, the test phase ensued. Participants received either an identity or location test, matching those used in Experiment 1. After responding, the next trial began. Trial order was randomized across participants and the test type was counterbalanced across trials. Participants could not anticipate the test type on a given trial. We recorded study time for each step of the study and updating procedures and recognition accuracy.

3.2 Results

For the memory test participants designated whether the presented information had been studied in the most recent, i.e. updated, grid. Half of the time, the test item came from the updated grid (*hits*) and half of the time it did not (*correct rejection*). There were two types of correct rejections. *Intrusions* involved information that had been originally studied, but then updated and *new, unstudied* information had not appeared earlier in the trial. Because these item types have differential implications for memory and intrusions only occur when the test type matches the information updated, we analyzed the item types separately. Analyses for both Hits and Correct Rejection of New Items used a 4(updated information: identity, location, combination, nothing) x 2(test type: identity, location) x 2(semantic relatedness: related, unrelated) mixed-factor ANOVA. Updated information and test type served as within-participant variables and semantic relatedness as a between-participant variable.

Hits. Participants had a higher hit rate for location (M = 0.92) compared to identity information (M = 0.87), $F(1,31) = 11.72$, $\eta_p^2 = .27$. Test type also interacted with the information updated, $F(3, 93) = 2.83$, $\eta_p^2 = .08$. Participants more accurately identified updated locations than updated identities, when no updating was required or when they had updated identities alone or identities and locations in combination. A different pattern emerged when they updated location information. After updating a location, participants recognized updated identities and locations equally well (see Fig. 5).

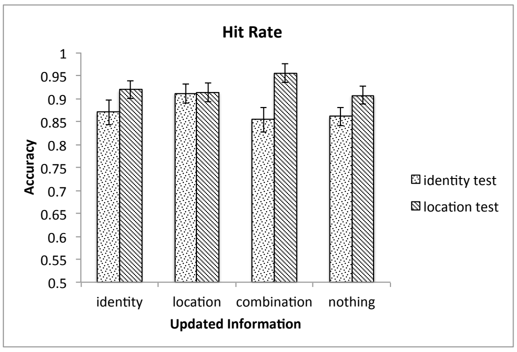

Fig. 5. Experiment 2 hit rates as a function of updated information.

Correct Rejection – New Items. Participants correctly rejected new locations (*M* = 0.93), not originally studied or updated in the grid, more accurately than new identities (*M* = 0.91), $F(1,31) = 4.55$, $\eta_p^2 = .13$. Test type also interacted with the information updated, $F(3, 93) = 2.98$, $\eta_p^2 = .09$. Participants more accurately rejected new locations compared to new identities after updating identity or location information. In contrast, if they updated both identity and location, they more accurately rejected new identities. If they did not need to update, they rejected new identity and location information equally well (see Fig. 6).

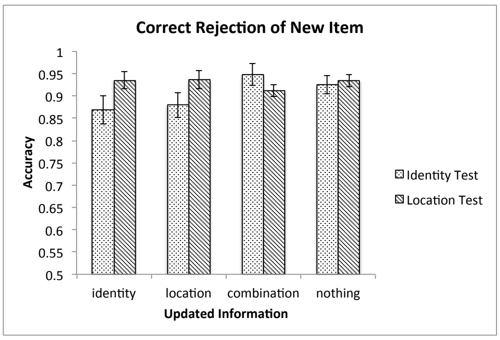

Fig. 6. Experiment 2 correct rejections of new information as a function of updated information.

Intrusions. Intrusions occurred when participants indicated that information from the first study grid, was included in a second, updated grid. Thus, the analysis involved a 2(amount updated: one aspect, both aspects) x 2(test type: identity, location) x 2(semantic relatedness: related, unrelated) mixed-factor ANOVA with amount updated and test type as within-participant variables and semantic relatedness as a between-participant variable.

Results showed a three-way interaction between amount updated, test type, and semantic relatedness, $F(1,31) = 4.49$, $\eta_p^2 = .13$. With semantically unrelated information, participants rejected identity and location intrusions at roughly equal rates, regardless of whether they had updated one aspect of the information or both. With semantically related information, participants more accurately rejected location than identity intrusions, whether they had updated one aspect or both, but more so if they had only updated one (see Fig. 7).

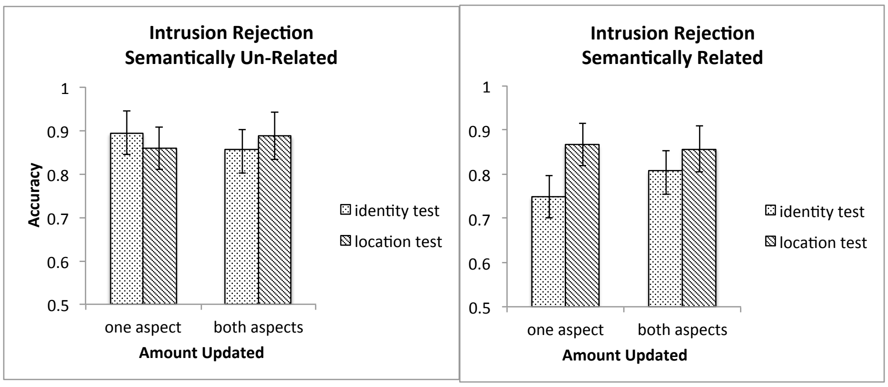

Fig. 7. Experiment 2 correct rejection of intrusions, i.e. previously studied but then updated information.

3.3 Discussion

Experiment 2 explored whether a local focus would impact the constituent parts of VSWM or the binding of location and identity. Contrary to our prediction, results showed better memory for location, similar to Experiment 1. Hit rate for locations exceeded that for identities. New locations were correctly rejected at a higher rate than new identities. Location intrusions, i.e. studied information that had been updated, were also correctly rejected more often than identity intrusions, particularly when the objects were semantically related.

A local focus through updating did lead to an intriguing finding. Focusing on location information appears to facilitate location and identity binding. Notably, when participants updated location information, their hit rate for location and identity information was equivalent. This contrasts with all other updating conditions (identity, both location and identity, or nothing). In all of these cases, hit rate for location exceeded that for identity. One interpretation for this finding is that focusing on location information, which is less effortful to process, leaves open cognitive resources for further processing object identity and binding it with that location. Although the case where nothing needs updating requires few cognitive resources, it does not also promote a local focus on any particular grid items.

5 Conclusions: Effects of Global and Local Processing on VSWM

The present work explored how global (Experiment 1) and local (Experiment 2) processing affect the components of and binding within VSWM. Experiment 1 induced global location processing by organizing locations into an interpretable whole [18]. Experiment 2 used task demands inherent in memory updating to promote local processing. Two main conclusions emerge from the results. First, location memory surpasses identity memory, regardless of processing focus (global or local). Thus, location information takes priority in VSWM. Second, beyond the location processing precedence, global and local processing changes how location and identity processing interact in VSWM.

Although VSWM involves location and identity, location information is better remembered. Our previous work [10] suggested less effortful processing of location information. In Experiment 1, by organizing location information and giving it a global interpretation, participants could better recognize previously presented location and reject location lures. Thus, spatial organization further enhanced location memory. Better location memory persisted with the local processing demands required to update individual aspects of the presented information. Even when participants updated identity information, they remembered locations more accurately.

A global or local focus does impact VSWM; the global or local focus changed how location and identity information interacted. While a global focus on location information improved location memory, it impaired identity memory, with strikingly higher identity false alarms when arrays were spatially organized. Whether this global processing effect is limited to the less cognitively demanding location processing or more generally to global processing is the focus of our current work. The effects of local processing do seem specific to the less demanding location processing. The results suggest an interesting notion for location-identity binding. Although we predicted improved memory for the aspect of focus, we found that when participants updated location information, identity memory improved. This suggests that focusing on less cognitively demanding location information facilitated binding of identity information. A similar focus on identity information did not impact either identity or location memory.

In sum, the components of VSWM, identity and location, have asymmetric processing demands, which impact how they interact during binding. The current studies, which manipulate global and local processing, further highlight these aysmmetries. Location appears less cognitive demanding and consequently is better remembered and can be further improved with spatial organization. Counterintuitively, focusing locally on location information improves identity memory and may aid binding in a way that a concomitant focus on identity information does not. This suggests that difficulties in binding location-identity information may result from difficulties processing or differentiating identity information.

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