The effect of presentation type on organization in visuospatial working memory (VSWM) was examined. Stimuli were presented sequentially or simultaneously at study, and participants made same/different judgements at test. The test array varied in four different spatial configuration conditions: one featuring no changes from study, one in which two items switched, one in which the same array repeated but in a different location, and one in which a completely novel test stimulus appeared. Results indicated the use of a global configuration for both simultaneous and sequential presentations and showed increased impairment of item-level knowledge with sequential presentations. Overall, these results support the use of a global configuration organization as a fundamental aspect of VSWM processing.

**Keywords**: Working memory; Visuospatial memory.
whether items in VSWM are stored independently from one another or whether they are stored relative to each other. If memory for an item within an array is not affected by changes in the surrounding items, it would suggest that items are stored independently in VSWM. Conversely, if memory is impacted by changes in the surrounding items, it would suggest relational organization within VSWM. Jiang et al. (2000) found support for the relational information hypothesis; memory was impaired when the task-irrelevant configuration changed between the memory image and the probe image.

Jiang et al. (2000) drew three primary conclusions about VSWM organization: (a) VSWM is organized based on a global spatial configuration with items represented relative to each other; (b) the formation of the configuration is flexible, such that both top-down and bottom-up processes work together to select important aspects needed to form the configuration; (c) information is organized hierarchically—thus, items in an array can be stored in relation to each other to form a global spatial configuration, but also information about the individual items must be stored.

In Jiang et al. (2000), however, only a simultaneous presentation was used. Recent research suggests that differences in VSWM processing exist between simultaneous and sequential presentations (Allen, Baddeley, & Hitch, 2006; Lecerf & de Ribaupierre, 2005), leaving open the issue of how the type of presentation at encoding impacts VSWM organization. That is, by only using a simultaneous presentation, the use of a global configuration organization may be emphasized within Jiang et al. (2000). Since a sequential presentation isolates each item during encoding, versus the overall configuration, organization may shift away from the global configuration to a more local, item-specific organization. Additionally, while prior work comparing sequential and simultaneous presentations has demonstrated an advantage for simultaneous presentations, currently there is little work examining why this advantage exists (see Allen et al., 2006; Alvarez & Thompson, 2009, for exceptions). Thus, the current experiment contributes to understanding of how processing differs between sequential and simultaneous presentations.

**Current experiment**

The current experiment examines the impact of encoding conditions on VSWM organization. Specifically, the experiment addressed whether a more local, item-based organization could be found with sequential presentation, or whether global configuration organization is a fundamental aspect of VSWM, as Jiang et al. (2000) suggested. If a global configuration of items is a fundamental property of VSWM, sequential presentations should show reduced performance compared to simultaneous presentations (since the global configuration itself is not present at encoding), but no advantage for individual items should be observed. Conversely, if both global and local codes can be utilized depending on initial encoding of items, simultaneous presentations might lead to global organization, whereas sequential presentations, in which items are presented individually, might be less likely to lead to global organization.

To examine global versus local organization within VSWM, the test array could vary in one of four ways: a no change condition where study and test arrays were identical (control condition); a new configuration condition where all items moved locations, creating a new array (control condition); an array shift condition with the same array repeated but “shifted” to a new location (global condition); and an item switch condition in which two items swapped positions (local condition). The key comparison across these conditions is between the array shift and item switch conditions. Specifically, evidence for a global configuration organization would be supported by higher performance in the array shift condition than in the item switch condition, and evidence for a more item-focused organization would be supported by the opposite pattern.

**Method**

**Participants**

A total of 80 participants taking an introductory psychology course at Colorado State University participated for course credit. Participants were
required to have self-reported normal or corrected vision in order to participate.

**Design**

A 2 (presentation type) × 4 (spatial configuration) mixed factorial design was used. Presentation type was manipulated between subjects: Half of the participants received simultaneous presentation and half sequential presentation (40 participants per group). In the simultaneous condition, all four stimuli in the visual array were presented all at once for 4 s. In the sequential condition, four stimuli were presented one at a time in a random order for 1 s each. The test array was presented simultaneously for both presentation conditions. Presenting the test array simultaneously could lead to an encoding specificity advantage for the simultaneous condition; however, Lecerf and de Ribaupierre (2005) showed an advantage for simultaneous presentations with both simultaneous and sequential test arrays. Thus, how the test array is presented does not seem to have a large effect on the advantage for simultaneous presentations.

The spatial configuration of the test array was manipulated within subjects with the following four conditions: no change, array shift, item switch, and new configuration. As shown in Figure 1, for the no change condition, the array presented the same items in the exact same location on the screen (i.e., study and test arrays were identical). The array shift condition maintained the spatial relationships between the items but moved the absolute position of the array (i.e., the whole array shifted in space). For both of these conditions, the correct response at test was “same” since the array itself did not change. For the item switch condition two objects (selected at random) were transposed. Hence the global configuration remained but the placement of two actual items within the array changed. In the new configuration condition, the global configuration was changed whereby all items moved locations creating an entirely new array (but featuring the same identity of items). In both of these latter two conditions the correct response was “different”. There were 25 trials of each condition, for a total of 100 trials. The trials were randomized for each participant.

**Stimuli and apparatus**

Attneave shapes (Attneave, 1957) were used as the stimuli for the task to prevent participants from recoding the stimuli verbally, ensuring that participants were using visuospatial representations to complete the task (Pearson, Logie, & Gilhooly, 1999). These polygons had four to seven sides, and approximate visual angle for the shapes ranged from 1.0° to 2.4°. Four shapes were

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**Figure 1.** Examples of the four spatial configuration conditions used in the experiment (not to scale).
presented on each trial. Each shape was used only once in the experiment.

The shapes were shown in black on a white background on 15-inch monitors with a screen resolution of 1,152 × 870. For the task, four shapes were randomly assigned to adjacent positions on an invisible 5 × 5 grid, with the constraint that no more than three stimuli appeared next to each other (either horizontally or vertically) so that no straight lines were formed.

Procedure
Participants were instructed to commit the spatial layout of the objects to memory. Participants first completed eight practice trials (two examples of each configuration type) with visual feedback.

Trials began with the word “READY” on the screen for 1 s, followed by a blank screen for 500 ms. Four stimuli were next presented in a format in accordance with the presentation condition (either all four stimuli simultaneously, or one at a time sequentially). A 5 s retention interval followed, composed of a blank screen for 500 ms, a mask of Xs for 500 ms, and the remaining interval time with a blank screen. A test array was then displayed, with all items shown simultaneously. The configuration of the test array items varied based on the four configuration conditions. The test array remained visible until a same/different response was made. Upon the completion of each trial, a blank screen appeared for 500 ms, and the next trial began until all 100 trials were completed.

Results
A criterion of \( p < .05 \) was used for all analyses. Percentage of correct responses was calculated for each condition. For the repeated measures analyses of variance (ANOVAs), the assumption of sphericity was not met, therefore degrees of freedom were adjusted using the Huynh–Feldt correction. Least significance differences were used for any post hoc comparisons.

Data were submitted to a 2 (presentation type) × 4 (configuration condition) mixed factorial ANOVA. This revealed a main effect of configuration condition, \( F(2.31, 180.23) = 76.82, \text{MSE} = 0.017, \omega^2 = .49 \), a main effect of presentation type, \( F(1, 78) = 31.7, \text{MSE} = 0.035, \omega^2 = .28 \), and a significant Configuration × Presentation interaction, \( F(2.31, 180.23) = 5.79, \text{MSE} = 0.017, \omega^2 = .06 \). Consistent with previous research, the simultaneous condition was significantly more accurate than the sequential condition (see Figure 2). For the configuration main effect, the item switch condition had significantly lower accuracy than all other conditions. No other comparisons reached significance.

Given the significant interaction, to examine accuracy across spatial configurations for sequential and simultaneous presentations, one-way repeated measures ANOVAs with four levels (configuration conditions) were calculated for each presentation condition. The sequential analysis revealed a main effect of configuration, \( F(2.47, 96.32) = 47.96, \text{MSE} = 0.02, \omega^2 = .54 \). Pairwise comparisons showed that the item switch condition was significantly lower than all other conditions. No other comparisons reached significance. This pattern is inconsistent with the hypothesis that sequential presentation improves item processing and instead suggests that item processing was impaired in the sequential condition.

Figure 2. Proportion correct from chance (.50) as a function of presentation type and spatial configuration condition (error bars represent standard error).
The simultaneous analysis also revealed a main effect of configuration, $F(2.16, 84.23) = 30.66$, $MSE = 0.014$, $\omega^2 = .42$. The pairwise comparisons showed that the item switch condition had significantly lower performance than all other conditions and that the array shift condition had significantly lower performance than the configuration change and no change conditions. The lower relative performance in the item switch condition for simultaneous presentations is consistent with an overreliance on the global configuration, leading to reduced item processing.

One alternative explanation for poor item processing following sequential presentation might be a strategic difference between responses in the two conditions, rather than the quality of information available in the representation. To examine this, both $d'$ (a measure of discriminability) and $C$ (a measure of response bias) were calculated for both presentation conditions. There was a significant difference between presentation conditions for response bias, $C$, with the sequential condition being significantly more likely to respond “same” ($M = 0.12$, $SD = 0.12$) than the simultaneous group ($M = 0.03$, $SD = 0.08$), $t(78) = 3.57$. However, consistent with the notion that performance is inferior with sequential presentation, lower discriminability was present for the sequential condition ($M = 1.66$, $SD = 0.68$) than for the simultaneous condition ($M = 2.22$, $SD = 0.63$), $t(78) = -3.10$.

### Capacity

In addition to analysing overall accuracy, the capacity, $K$ (see Cowan, 2001; Pashler, 1988; Vogel, Woodman, & Luck, 2006), of VSTM between sequential and simultaneous conditions was examined. $K$ is a measure of items that are currently available in working memory with $K = S^*(H + C - 1)$ where $S$ is the set size of the array, $H$ is the hit rate, and $C$ is the correct rejection rate (Vogel et al., 2006).

In the current experiment, $K$ differed between sequential ($M = 1.65$, $SD = 0.83$) and simultaneous ($M = 2.61$, $SD = 0.62$) conditions, with VSTM capacity being significantly higher in the simultaneous group, $t(78) = -5.89$. These capacity estimates are lower than those reported in previous experiments (e.g., Vogel, Woodman, & Luck, 2001; Vogel et al., 2006), which could be due to the more complex stimuli used in this experiment (Alvarez & Cavanagh, 2004), or due to increased item similarity leading to comparison errors between study and test arrays (Awh, Barton, & Vogel, 2007). Despite capacity estimates that are lower than those in other experiments of this type, however, the current results show that sequential presentations lower VSTM capacity compared to simultaneous presentations, suggesting that capacity is related to initial encoding conditions.

### GENERAL DISCUSSION

This study examined whether a global spatial configuration organization in VSTM was a fundamental property of VSTM, or whether organization varies depending on how information was initially encoded. Different presentation types were compared at study with four different spatial configurations at test. The results support an organization in VSTM based on a global spatial representation for both simultaneous and sequential presentations. This is consistent with the results from Jiang et al. (2000) and, as the current experiment uses a different task and stimuli, provides converging evidence for a global representation as a fundamental aspect of visuospatial processing.

**Organization in VSTM and global spatial configurations**

The key aspect to the current findings is that performance consistent with a global configuration is still in evidence following sequential presentation, adding further credibility to this type of representation being a fundamental aspect of visuospatial processing. This adds further support to Jiang et al.’s (2000) suggestion that a global spatial configuration representation in VSTM is a fundamental aspect of visuospatial processing. However, while this experiment does provide strong initial support for Jiang et al. (2000), it is important to note that other issues could lead to
changes in how information is organized within VSWM. For example, in the current experiment the test conditions (i.e., using a simultaneous test) used could have encouraged the use of a spatial configuration over an item-focused representation, an issue that should be addressed in future research to further examine the generalizability of a spatial-configuration-based organization in VSWM.

While the spatial configuration conditions were designed to compare an organization based on relational information (i.e., array shift condition) versus a more item-focused organization (i.e., item switch condition), it is possible that the conditions over- or underestimate that particular level of knowledge. Specifically, given the low performance in the item switch condition, it is possible that condition was more difficult than the other configuration conditions. Alvarez and Thompson (2009) recently argued that feature switch tasks underestimate the capacity of VSWM (specifically the binding capacity of features into objects) because people are able to accurately report location and identity of items in a cued recall task (compared to a change detection task). More specifically, Alvarez and Thompson (2009) suggest that poor performance in feature switch tasks reflects fragility of maintenance of visuospatial information, and the swapped items in memory are overwritten by the test items.

In line with this view, the current experiment showed a decrement in performance for the item switch condition in which participants are asked to store the binding of the shapes to their respective locations (versus details of the items themselves). Thus, the low performance in the current data for the item switch condition may underestimate item-level knowledge. However, even if the item switch condition underestimates overall item memory, it is clear that the type of presentation used at study can lead to drastic performance differences in detecting item switches.

Encoding in VSWM

This experiment supports previous work (e.g., Allen et al., 2006; Lecerf & de Ribaupierre, 2005) showing an encoding advantage for simultaneous presentations and suggests that this advantage may be due to improved organization in VSWM when items are presented simultaneously. There was evidence that participants were able to form a global configuration with sequential presentations, but performance was significantly worse, suggesting that spatial configuration organization was incomplete.

Allen and colleagues (2006), in line with Alvarez and Thompson (2009), offer a different, though not necessarily contradictory, view as to why simultaneous presentations are superior. In their experiments, Allen et al. (2006) argued that the bindings of features is fragile and susceptible to overwriting from subsequent visual information, especially for items presented earlier. Thus, lower performance in the sequential condition in the current experiment could also be due to such an overwriting process, making it difficult to form a global spatial representation as later presented items overwrite the earlier items. This difficulty in maintaining items long enough to form a global representation could also explain the lower capacity estimate for sequential presentations.

This work by Allen et al. (2006) is supported by Darling, Della Sala, and Logie (2009) in which sequential presentations did not show a disadvantage compared to simultaneous presentations when only identity (or appearance) or location had to be remembered. This suggests that the disadvantage for sequential presentations shown previously could be due to a deficit in binding, as argued by Allen et al. (2006). This dissociation between item and location memory also supports the multiple-component model of VSWM (e.g., Logie, 2003; Logie & van der Meulen, 2009). In order to fully understand the nature of VSWM organization, the current results should be extended to different task and test conditions, particularly to examine how configurations may differ based on the type of information (e.g., bound information versus specific features) that is required to complete the task, and how these factors may interact with encoding conditions.

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