

2010

Attention is not required to maintain feature bindings in visual working memory

Amanda van Lamsweerde

Louisiana State University and Agricultural and Mechanical College

Follow this and additional works at: https://digitalcommons.lsu.edu/gradschool_theses



Part of the [Psychology Commons](#)

Recommended Citation

van Lamsweerde, Amanda, "Attention is not required to maintain feature bindings in visual working memory" (2010). *LSU Master's Theses*. 4247.

https://digitalcommons.lsu.edu/gradschool_theses/4247

This Thesis is brought to you for free and open access by the Graduate School at LSU Digital Commons. It has been accepted for inclusion in LSU Master's Theses by an authorized graduate school editor of LSU Digital Commons. For more information, please contact gradetd@lsu.edu.

ATTENTION IS NOT REQUIRED TO MAINTAIN FEATURE BINDINGS IN VISUAL
WORKING MEMORY

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Arts

in

The Department of Psychology

by
Amanda van Lamsweerde
B.A., University of California, Irvine, 2006
May 2010

TABLE OF CONTENTS

List of Figures.....	iii
Abstract.....	iv
Introduction.....	1
Attention Is Required to Maintain Feature Bindings.....	2
Attention Is Not Required to Maintain Feature Bindings.....	4
The Current Study.....	6
Experiment 1.....	8
Methods.....	8
Participants.....	8
Apparatus.....	8
Stimuli.....	8
Procedure.....	9
Results.....	10
Discussion.....	12
Experiment 2.....	15
Methods.....	17
Participants.....	17
Apparatus.....	17
Stimuli.....	17
Procedure.....	18
Results.....	19
Is Attention Required to Maintain Feature Bindings?.....	19
Are Features and Bindings Transferred to Long-Term Memory?.....	21
Discussion.....	23
General Discussion.....	26
Conclusion.....	29
References.....	30
Vita.....	32

LIST OF FIGURES

1. Stimuli for Experiments 1 and 2	9
2. Procedure for Experiment 1	11
3. Results of Experiment 1	13
4. Procedure for Experiment 2	20
5. Results of Experiment 2	21
6. Dwell Time at Each Lag	23

ABSTRACT

Attention plays an important role in the formation of accurate feature bindings. However, the role of attention in maintaining feature bindings is not as well established. Some research supports the theory that attention is needed to maintain feature bindings in visual working memory (VWM), while other research suggests that bindings remain intact after the withdrawal of attention. Experiment 1 of current study tested this hypothesis by replicating the findings that feature bindings are more difficult to remember than individual features in a whole report change detection task. Experiment 2 directly measured attention through eye tracking and manipulated whether a change occurred to an object within the focus of attention, a previously attended object, or an unattended object. The results of Experiment 2 suggest that attention is not required to maintain feature bindings. Together, the results of the current study suggest that while feature bindings may be more difficult to remember than individual features in some instances, attention is not required to maintain feature bindings in VWM.

INTRODUCTION

Spatial attention has long been indicated as an important factor in the formation of accurate feature bindings (Hyun, Woodman, & Luck, 2009; Prinzmetal, Presti, & Postner, 1986; Shafritz, Gore, & Marois, 2002; Treisman, Sykes, & Gelade, 1977; Treisman & Gelade, 1980; Treisman, 1999; Tsal & Lavie, 1988). It has been proposed that the visual world can be divided into many separable dimensions (such as color, shape, or orientation), with various values (features) along these dimensions (square, blue, vertical; Treisman & Gelade, 1980). Features of objects can be perceived preattentively; however, prior to focused attention on objects, these features are free floating, not integrated into objects (Treisman, Sykes, & Gelade, 1977; Treisman & Gelade, 1980). In order to detect a unified object, attention must be directed toward it. Once attention is directed to an object, it can be stored in visual working memory (VWM), a limited capacity memory system that can maintain approximately 2-4 objects (Alvarez & Cavanaugh, 2004; Eng, Chen, & Jiang, 2005; Luck & Vogel, 1997). However, it is unclear what happens to the feature bindings of an object after attention has been withdrawn and directed toward a new object.

There are two groups of theories that address the role of attention in feature binding maintenance. One group suggests that once attention is withdrawn from an object, the features are no longer bound to each other, and the bindings are lost (Fougnie & Marois, 2009; Treisman & Zhang, 2006; Wheeler & Treisman, 2002; Wolfe, Klempe Dahlen, 2000). Therefore, the individual features of an unattended object in VWM can be remembered, but not the feature bindings. The second group suggests that attention is not required to maintain feature bindings and once attention is withdrawn from an object, the

object can be represented in VWM as an integrated whole (Gajewski & Brockmole, 2006; Vogel, Woodman, & Luck, 2001; Johnson, Hollingworth, & Luck, 2008; Woodman & Vogel, 2008). These two theories are the topic of interest in the current study.

Attention Is Required to Maintain Feature Bindings

Wheeler & Treisman (2002) suggested that once attention is withdrawn from an object, its features are no longer bound to one another. Evidence for this hypothesis comes from a change detection task examining performance for detecting when two objects swap features compared to when objects change to completely new features. In this experiment, an array of 2, 4, or 6 objects was presented for 150ms (study array), followed by a 900ms interstimulus interval (ISI), and then a second array (test array) of objects (whole report experiment). Participants indicated whether or not they detected a change to any of the objects from the first array to the second. Four types of changes could occur, blocked within subjects. In one block, two objects changed to colors not present on the first screen (color condition), in a second block, two objects changed to shapes not present on the first screen (shape condition), in a third, two objects changed either color or shape (2-feature condition), and in a fourth block, two objects traded features with one another (binding change condition; for example, an orange circle and a blue square in the first array may change to a blue circle and an orange square in the second array). In all conditions, half of the trials were changes and half were not; participants indicated whether they detected a change. Also, in all four conditions, all of the objects swapped locations with one another from the study array to the test array to prevent binding of individual features to locations. Wheeler and Treisman (2002) found

that performance was highest for color changes, 2-feature and shape performance were equal to each other, and performance for binding changes was lowest. In a second experiment, only one object was presented on the test array (single object probe experiment). In this experiment, binding change performance was equal to shape change performance. The authors suggested that the enhanced binding performance in the single object probe relative to the whole report experiment reflected a need for attention in feature binding maintenance. In the whole report experiment, the test array was perceptually complex, so attention was needed to form new feature bindings. Attention was removed from the old items and directed toward the new array of objects, causing the removal of feature bindings from the study array. However, in the single object probe experiment, the item can be perceived more easily and attention does not need to be redirected to the new item. The authors concluded that feature bindings could be remembered as well as individual features, but only as long as attention is not removed from the bound object.

Fougnie and Marois (2009) tested the role of attention in maintaining feature bindings by introducing an attention-demanding task in the middle of a change detection task. An array of three objects was presented for 400ms, followed by an 800ms ISI, and then a multiple object tracking (MOT) task. In the MOT task, participants were instructed to follow three moving targets within an array of distractors. When the objects stopped moving, participants were shown a single object in the center of the array and had to indicate whether that object was the same as an object in the study array at the beginning of the trial. Then, an item from the MOT task was probed, and participants indicated whether this object was a target. The types of changes that could occur between study and

test were the same as in Wheeler and Treisman (2002): a block of color changes, a block of shape changes, a block of 2-feature changes, and a block of binding changes. If attention is required to maintain feature bindings, a task that disrupts attention during maintenance should disrupt feature bindings more than individual features. Although performance was reduced in both the shape and binding conditions (relative to control trials without an MOT task) the MOT task disrupted feature bindings more than shapes. This suggests that attention is required to maintain feature bindings in VWM. However, other research that disrupted attention between study and test has suggested that attention is not required to maintain feature bindings.

Attention Is Not Required to Maintain Feature Bindings

Johnson et al. (2008) found evidence, using a task identical to that of Wheeler and Treisman (2002), to support the theory that attention is not required to maintain bindings. Johnson et al. (2008) replicated the design of the Wheeler & Treisman (2002) experiment, but failed to find a difference between the binding and shape condition in the whole report experiment. In addition, Johnson et al. (2008) ran a single-object probe experiment and again found that performance for binding changes was equal to that of shape changes. Furthermore, in an additional experiment, the authors attempted to distract attention by adding a visual search task during the ISI of a change detection task. In this change detection task, colored bars could change either color or orientation in one block (2-feature condition), or two objects could swap features (binding condition). They predicted that if attention is needed to maintain feature bindings, then the visual search task should disrupt memory for bindings to a greater degree than memory for individual features. Therefore, performance for binding changes should be lower than performance

for either color or orientation changes. Overall, participants performed worse on the binding condition than the 2-feature condition. However, within the 2-feature condition, color change detection performance was higher than orientation performance.

Comparisons of the binding performance to the orientation trials in the 2-feature condition showed that binding performance was slightly better than orientation performance. Therefore, disrupting attention did not harm memory for bindings more than individual features, suggesting that attention is not required to maintain feature bindings.

Gajewski & Brockmole (2006) also attempted to test whether attention is needed to maintain feature bindings by distracting attention. In their task, an array of objects was presented in a circle, followed by a blank screen. Then, a cue appeared in a location where an object had been present in the study array. This was followed by another blank screen, followed by a probe in a different location from the cue. Participants reported the shape, color, or shape and color (binding test) of the object that had appeared in the probed location. The authors predicted that if attention was required to maintain feature bindings, the cue should serve to distract attention from the probed object, thus removing bindings for the probed object. As a result, participants should be able to remember only one feature most of the time when asked to report both. However, participants remembered both features of a probed object as frequently as they remembered one feature, suggesting that attention is not needed to maintain feature bindings. However, it is possible that both shape and color were remembered because they were bound to their location, not each other. In fact, this is very likely because location was used to cue

memory, and research demonstrates that feature bindings are readily bound to their spatial locations (Treisman & Zhang, 2006).

The Current Study

The current experiments will address the question of whether attention is required to maintain feature bindings by directly measuring attention through eye tracking. Given the conflicting results of the whole report experiments of Wheeler & Treisman (2002) and Johnson, Hollingworth, and Luck (2008), Experiment 1 will replicate this experiment, with two changes. Instead of using set sizes of two, four, and six, performance at set sizes four, six and eight were measured. Performance at set size two was identical across all conditions for Wheeler and Treisman (2002) and Johnson, Hollingworth, and Luck (2008). For Wheeler and Treisman (2002), binding performance became lower than shape performance only at larger set sizes. Therefore, in the current study, set size 8 was used to test the idea that it is more difficult to remember feature bindings as set size increases. If attention is necessary for maintaining bindings in VWM, binding performance should decrease relative to individual feature performance (in this case shape, the more difficult feature to remember) with increasing set size. As set size increases, the test array becomes increasingly complex, requiring attention to form the new feature bindings. This leaves fewer attentional resources available to maintain previous feature bindings. In addition, eye movements were tracked in this experiment. Eye movements toward an object on the study array would indicate that a single object was in the focus of attention during encoding. This seems unlikely, given that the first array is presented for only 150ms and the objects are close enough to each other that the visual detail for the objects can be perceived from a central fixation. However, to test

this, eye movements on the study array were monitored. A single fixation in the center of the study array would indicate that attention is spread globally to all objects during encoding.

Experiment 2 will address the question of whether attention is required to maintain feature bindings by allowing shifts of attention during encoding (the study array). The changing object was controlled, depending on the order of fixations in the study array. In this way, attention to a changing object can be directly manipulated, in contrast to past research that attempted to disrupt attention to all objects (Johnson, Hollingworth, & Luck, 2008; Fournie and Marois, 2009). Performance should be highest for all types of changes for the object within the focus of attention compared to objects not inside the focus of attention. However, if attention is required to maintain feature bindings, binding change detection performance should decrease dramatically for all objects not within the focus of attention, compared to performance for detecting changes to individual features. That is, for any object not within the focus of attention, binding changes should be more difficult to detect than single feature (shape) changes.

EXPERIMENT 1

Methods

Participants. Fifteen undergraduate students and one graduate (9 female, 7 male, average age 20) participated in this experiment. Undergraduate students received credit in psychology courses. All participants had normal or corrected to normal vision and normal color vision.

Apparatus. An Eyelink II head mounted eye tracker was used to track eye movements, and a chin rest was used to prevent head movements. Before every block, calibration and validation procedures were conducted and drift corrections were conducted between each trial. The SR Research Experiment Builder program was used to create and run the experiment and eye tracking data was analyzed with the Data Viewer program.

Stimuli. Ten possible shapes, in ten highly discriminable colors (see Figure 1) were used, each subtending a visual angle of approximately 0.73° (from a viewing distance of 45cm), presented in eight possible locations of a 3x3 grid (the center position never containing an object) subtending an $8.6^\circ \times 8.6^\circ$ region. The same shapes and colors were used as in the Wheeler & Treisman (2002) experiment, with the addition of two colors and two shapes to accommodate an eight object set size; set sizes 4, 6 and 8 were used. The same colors and shapes never appeared twice within an array.

Four change type conditions (color, shape, 2- feature, binding; see Figure 2) were blocked within participants, each block containing 144 trials and 32 practice trials for a total of 576 test trials and 128 practice trials. On change trials in the color condition, two of the objects on the test array changed to new colors not present on the study array. In

the shape condition, two objects changed to new shapes. In the 2-feature condition, half of the changes were color changes, while half were shape changes. On the test array, participants were probed about which type of change might have occurred. In the binding condition, two of the objects traded features. For example, a blue circle and an orange square in the study array could change to an orange circle and a blue square in the test array. In all four conditions, half of the trials were change trials and half were no change trials. Set sizes of the arrays were randomly distributed within blocks (48 trials, half change and half no change, for each set size). All of the objects traded places with one another from the first screen to the second to prevent binding of features to their locations.

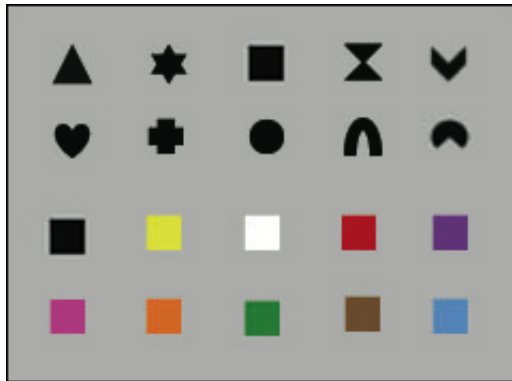


Figure 1: Stimuli for Experiments 1 and 2. Ten shapes and ten colors were used to create a set of 100 objects. No two objects with the same shape or color appeared within an array.

Procedure. An array was displayed for 150ms, followed by a 900ms ISI, and then a new array of objects until a response was given. Participants indicated whether they detected a change to any of the objects by pressing two buttons on a controller, one for yes and one for no. Participants completed all four change type conditions; the order of the conditions was randomly determined for each participant.

Participants performed a verbal suppression task to prevent verbal coding of the stimuli. A subvocal a suppression task was used similar to that used by Luck & Vogel (1997) to prevent head movements from talking. Participants were presented with three random numbers (0-9) before each trial and were asked to silently repeat them during the trial. Participants reported the numbers back at the end of the trial. To report the numbers, a screen with the numbers 0-9 was displayed. Participants reported a number by looking at it until it turned red, and then pressing a button on a controller (a different button from the ones they used to report yes or no to a change).

Results

A repeated measures ANOVA with condition (color, shape, 2-feature, and binding) and set size (four, six, and eight) as within subjects factors revealed a main effect of set size $F(2,30) = 33.66, p < .001$, partial $\eta^2 = .69$ and condition $F(3,45) = 45.98, p < .001$, partial $\eta^2 = .75$ and no interaction, $F(6,90) = 1.47, p = .20$, partial $\eta^2 = .09$ (see Figure 3). Pairwise comparisons revealed that performance in the color condition ($M = .83$ $SD = .10$), was significantly higher than all other conditions, all $p < .001$. 2-feature performance ($M = .69$ $SD = .08$), was higher than shape performance ($M = .65$ $SD = .07$), and binding performance ($M = .62$ $SD = .08$), all $p < .01$. In addition, shape performance was marginally higher than binding performance, $p < .10$. Planned comparisons between the shape and binding conditions showed that there was no difference in performance between shape ($M = .70$ $SD = .06$) and binding ($M = .70$ $SD = .11$) at set size 4, $t(15) = .22$, ns; however, there was a difference at set size 6 (shape $M = .63$ $SD = .07$, binding $M = .58$ $SD = .08$), $t(15) = 2.41$ $p < .05$. This trend continued at set size 8, but the differences were not significant (shape $M = .62$ $SD = .08$, binding $M = .57$

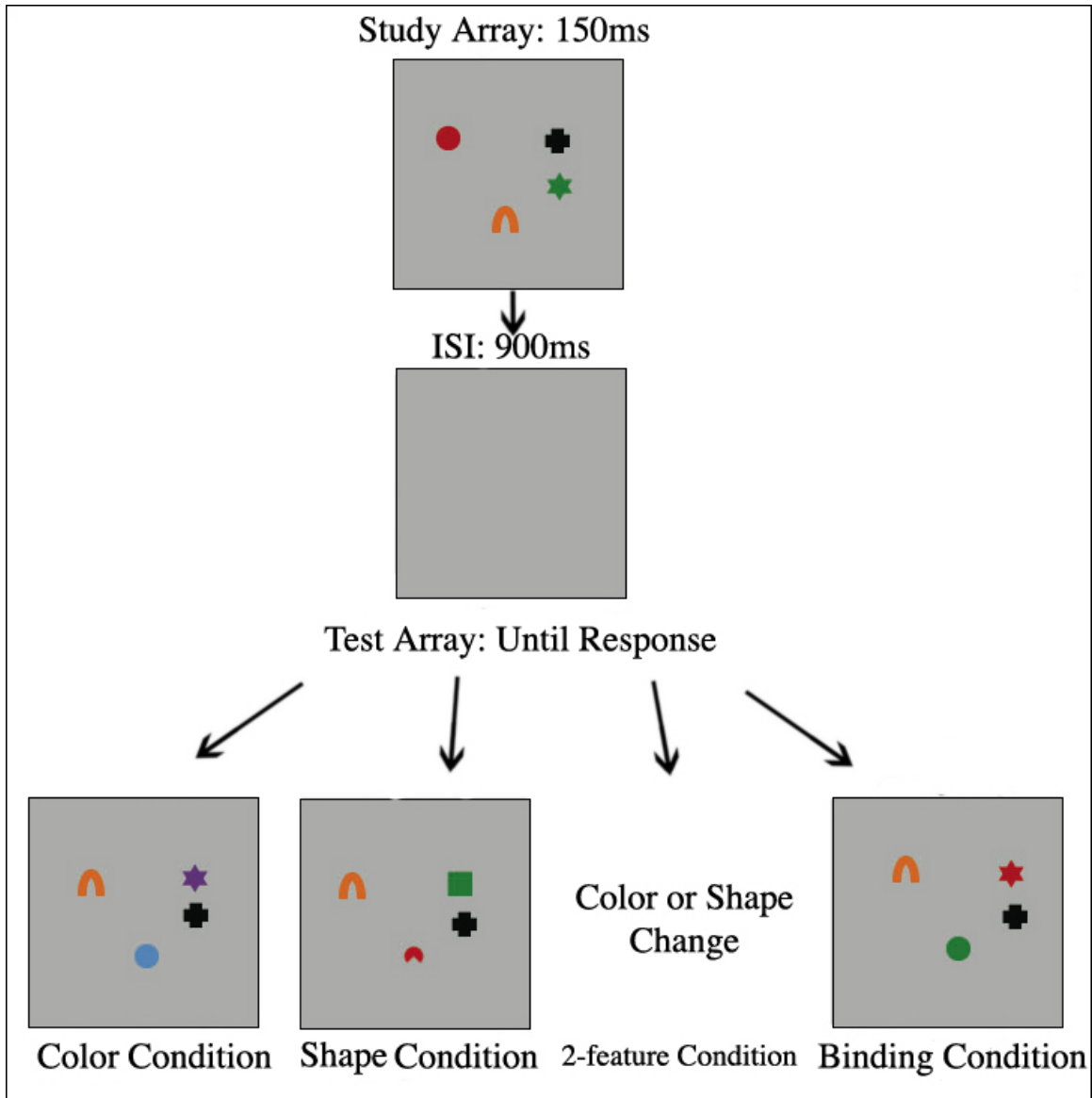


Figure 2: Procedure for Experiment 1. All objects switched locations from the test array to the study array. In the color condition, two objects changed to two colors not present on the study array; in the shape condition, two objects changed to shapes not present on the study array; in the 2-feature condition, half of the trials were color changes and half were shape changes; in the binding condition, two objects traded features from the study array to the test array. In each condition, half the trials were change trials and half were no change trials.

$SD = .08$), $t(15) = 1.43$ $p = .17$. This replicates the findings of Wheeler and Treisman (2002), who found a difference between the shape and binding conditions at larger set sizes.

Pairwise comparisons also revealed that performance at set size 4 ($M = .76$ $SD = .08$) was better than performance at set size 6 ($M = .68$ $SD = .09$), $p < .01$, which was marginally higher than performance at set size 8 ($M = .65$ $SD = .08$), $p = .06$.

Eye movements during the presentation of the first array were measured. Participants only made a fixation away from the center of study array on 5% of the trials. This suggests that participants did not focus attention on any individual item during encoding, but attempted to spread attention globally to all objects in the array.

Discussion

The results of Experiment 1 are consistent with those of Wheeler and Treisman (2002). That is, it was more difficult for participants to detect changes to feature bindings than changes to shape (the more difficult to remember feature). According to Wheeler and Treisman (2002), this suggests that feature bindings require attention to be maintained in VWM. In addition, the difference in performance between the shape and binding conditions occurred at larger set sizes (six and eight) but not a small set size (four). As set size increases, the perceptual difficulty of forming feature binding increases. Therefore, attentional resources needed to form new feature bindings for the objects on the test array. This attention was keeping the original feature bindings together, so when attention shifted from the objects on the study array to the objects on the test array, the feature bindings of the original objects were lost. Lack of attentional resources during encoding were not assumed to be responsible for lower binding

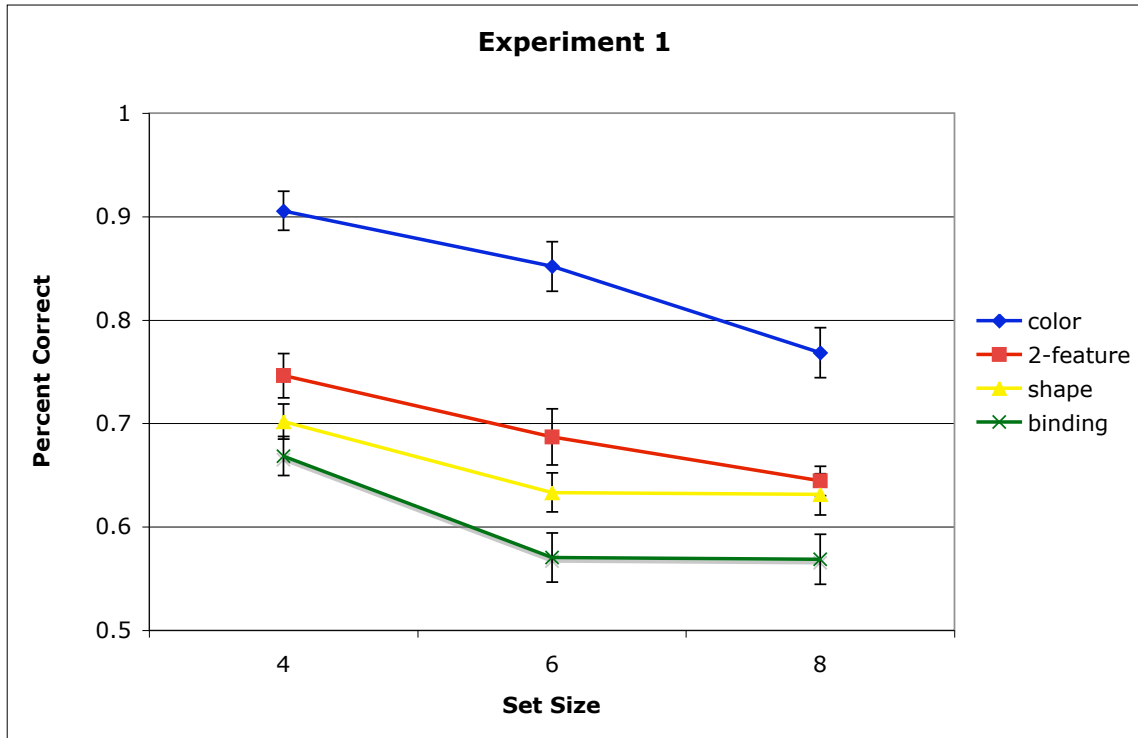


Figure 3. Results of Experiment 1. Performance was highest for color the color condition, followed by 2-feautre condition, the shape condition, and finally the binding condition. Performance decreased with increasing set size.

performance, because if a single object is probed at test, binding performance remains as high as shape performance (Wheeler & Treisman, 2002). This suggests that the bindings are formed during encoding, but that a whole array at test disrupts them because it requires a shift of attention. Therefore, attention is required during maintenance to keep the feature bindings together. However, some research has found that disrupting attention during maintenance does not impair memory for bindings more than single features (Johnson, Hollingworth, & Luck, 2008; Gajewski and Brockmole, 2006), which calls this attention conclusion into question. One shortcoming of these previous studies is that attention to individual objects was not measured.

In Experiment 1 of the current study, participants moved their eyes away from the center of the study array very rarely (5%), which supports the idea that serial shifts of attention are not occurring during encoding, and that attention spread globally to all objects. However, this does not answer the question of what information is within the focus of attention during encoding or maintenance. Also, attention to a changing object is not directly controlled. A more direct measure of the role of attention in feature binding maintenance would be to directly measure serial shifts of attention, and examine binding for attended versus unattended objects.

EXPERIMENT 2

In Experiment 2, attention to a changing object was measured directly through the use of eye tracking. Research indicates that people generally fixate where they are attending and a shift of attention to a new object is followed by a saccade toward it (Land, Mennie, & Rusted, 1999; Hayhoe, 2000). Therefore, eye movements are a good measure of the locus of attention; in this experiment, fixation was used to determine if an object was attended. Participants viewed a study array of eight objects and were allowed to freely fixate objects in the array. Unlike Experiment 1, the objects were far from each other, so that it was difficult to perceive the visual details of an object from a central fixation. This encouraged serial shifts of attention in the study array. As soon as a saccade was detected within a 3.8° visual angle square around the fifth object, the screen became blank. Research has demonstrated that with the initiation of a saccade, the focus of attention has moved to the saccade target; therefore, this fifth object was considered to be the object within the focus of attention (Bays & Husain, 2008). The four objects fixated prior to the attended were considered to be a previously attended object. Any object that was not fixated was considered an unattended object. Following the study array and an ISI, a screen with a single object in the center was presented. Participants then determined whether the color, shape, or color-shape combination had been present in the first array. If attention is required to maintain feature bindings, participants should be poor at detecting binding changes for all objects except the object that was attended when the array disappeared. However, performance should remain high for detecting changes to individual features as long as the changing object was still maintained in VWM. In contrast, if attention is not required to maintain feature bindings, performance for feature

bindings should equal that of individual features (shape, the more difficult to detect feature).

The methodology of Experiment 2 allowed participants to fixate each object as long as they wanted on the study array (compared to Experiment 1, where participants had only 150ms to view all objects). However, it is possible that the fixation duration may differ as a function of lag (that is, participants may spend more time viewing the first object on each screen, and less time viewing each object after that). This may allow participants to form more durable representations for the objects at the beginning of the viewing sequence, leading to subsequent storage of this information in long-term memory (LTM). While VWM has a small capacity (3-4 objects, Luck & Vogel, 1997), LTM is a large capacity, robust memory system, capable of storing detailed visual information for thousands of objects (Brady, Konkle, Alvarez, & Oliva, 2008; Hollingworth, 2004). Hollingworth (2004) suggested that visual representations of objects in on-line scene viewing is dependent on both VWM and LTM; as a person looks from object to object, information is transferred from VWM to LTM. Hollingworth (2004) found that participants were able to detect changes to the first objects viewed in a natural scene, even after viewing ten or more intervening objects (well outside the capacity of VWM), which suggests the first objects were not discarded, but rather stored in LTM. It is possible that the first objects viewed in Experiment 2 could similarly be transferred to LTM. If this is the case, displaying performance by lag should reveal a U-shaped curve, with high performance for the first and last objects fixated (reflecting good performance for information in LTM and VWM, respectively), with lower performance in the middle. Some research has suggested that in VWM tasks such the ones in the

current study, it may be difficult to transfer either feature bindings or individual features into long-term memory (LTM), although repeated, consistent exposure of bindings may result in transfer to LTM (Logie, Brockmole, & Vandenbroucke, 2009). The question of whether either individual features or feature bindings in Experiment 2 were transferred to LTM was examined through analysis of the amount of time viewing each object and by a trend analysis for each condition. If information from the display was encoded into LTM, this may be reflected by longer viewing times for the first objects fixated and performance should reflect a quadratic trend that indicates a primacy and recency effect.

Methods

Participants. Seventeen students, 12 undergraduate students and 5 graduate students, including the author (11 female, 6 male, average age 22 years), participated in this experiment. Undergraduate students received course credit for participation. All participants had normal color vision and normal or corrected to normal vision.

Apparatus. As in Experiment 1, eye movements were tracked with an Eyelink II head mounted eye tracker. A chin rest was used to prevent head movements. Before every block, calibration and validation procedures were conducted and drift corrections were conducted between each trial. The SR Research Experiment Builder program was used to create and run the experiment and eye tracking data was analyzed with the Data Viewer program.

Stimuli. The same stimuli were used as in Experiment 1, with the exception that only set size 8 was used. In addition, all 8 objects were presented in a circle subtending 13.7° visual angle from the center of the screen (from a viewing distance of 45cm). This

manipulation encouraged participants to make eye movements to individual objects, as it was difficult to perceive the visual details of the objects from a central fixation.

Procedure. Encoding time was increased for this experiment, and was dependent upon fixations. Participants were presented with 8 objects in a circle, and were allowed to make four full fixations on the screen, and direct their eyes toward a fifth object before the onset of the ISI. A fixation was considered to have been directed toward the fifth object if it entered a square that subtended 3.8° visual angle around the object. After 900ms, a test screen was presented with one object presented in the center (see Figure 4). A single object, rather than a whole array, was used to control which object would be in the focus of attention at test. In addition, presenting this object in the center of the screen ensured that the feature information could not be remembered through binding to location. The object presented on the center of the screen was determined based on the order of fixations on the first screen. Specifically, the object presented on the second screen was the object at each lag (0-5) an equal number of times. Lag 0 was the object that the saccade was directed towards at the onset of the ISI, lag 1 was the object that was fixated just before lag 0, and so on, until lag 4, which was the first object fixated. All objects that were not fixated were considered unattended, and were analyzed together in their own group (labeled lag 5 for convenience). At each lag, half of the trials were change trials and half were no change; participants indicated whether they detected a change by pressing one of two buttons on a controller. Changes were grouped into four blocks, as in Experiment 1: color changes, shape changes, color or shape changes (2-feature condition) and binding changes. On the test screen, participants were asked whether the color, shape, or color-shape combination of the object was present in the first

screen. In the 2-feature condition, participants were probed about either color or shape changes. Each block contained 82 trials; 10 practice trials and 72 test trials (12 at each lag, half change and half no change for each lag), for a total of 328 trials. In the 2-feature condition, half of the trials at each lag were color trials, and half were shape trials, half of each of these were change and half were no change. The same subvocal suppression task was used as in Experiment 1.

Results

Is Attention Required to Maintain Feature Bindings? A repeated measures ANOVA with lag (0-5) and condition (color, shape, 2-feature, and binding) as within subjects factors revealed a main effect of condition $F(3, 48) = 18.40$, $p < .001$, partial $\eta^2 = .54$ and a main effect of lag, $F(5, 80) = 15.17$, $p < .001$, partial $\eta^2 = .49$ (see Figure 5). A lag x condition interaction was not significant, $F(15, 240) = 1.29$, $p = .21$, partial $\eta^2 = .07$. Pairwise comparisons revealed that performance in the color condition ($M = .78$, $SD = .13$), was higher than the three other conditions, all $p < .001$. In addition, 2-feature performance ($M = .68$, $SD = .15$), was higher than the binding condition ($M = .63$, $SD = .18$), $p < .05$ but not the shape condition ($M = .65$, $SD = .17$). In addition, performance in the shape and binding conditions did not differ from each other.

Pairwise comparisons also revealed that performance was better at lag 0 than all other lags ($M = .80$, $SD = .16$), all $p < .01$. In addition, performance for all attended items (lags 0 – 4) was better than performance for unattended items ($M = .58$, $SD = .16$), all $p < .01$. Performance at lag 4 ($M = .71$, $SD = .15$) was better than performance at lag 2 ($M = .65$, $SD = .16$), $p < .05$, but not at lag 3 ($M = .69$, $SD = .17$).

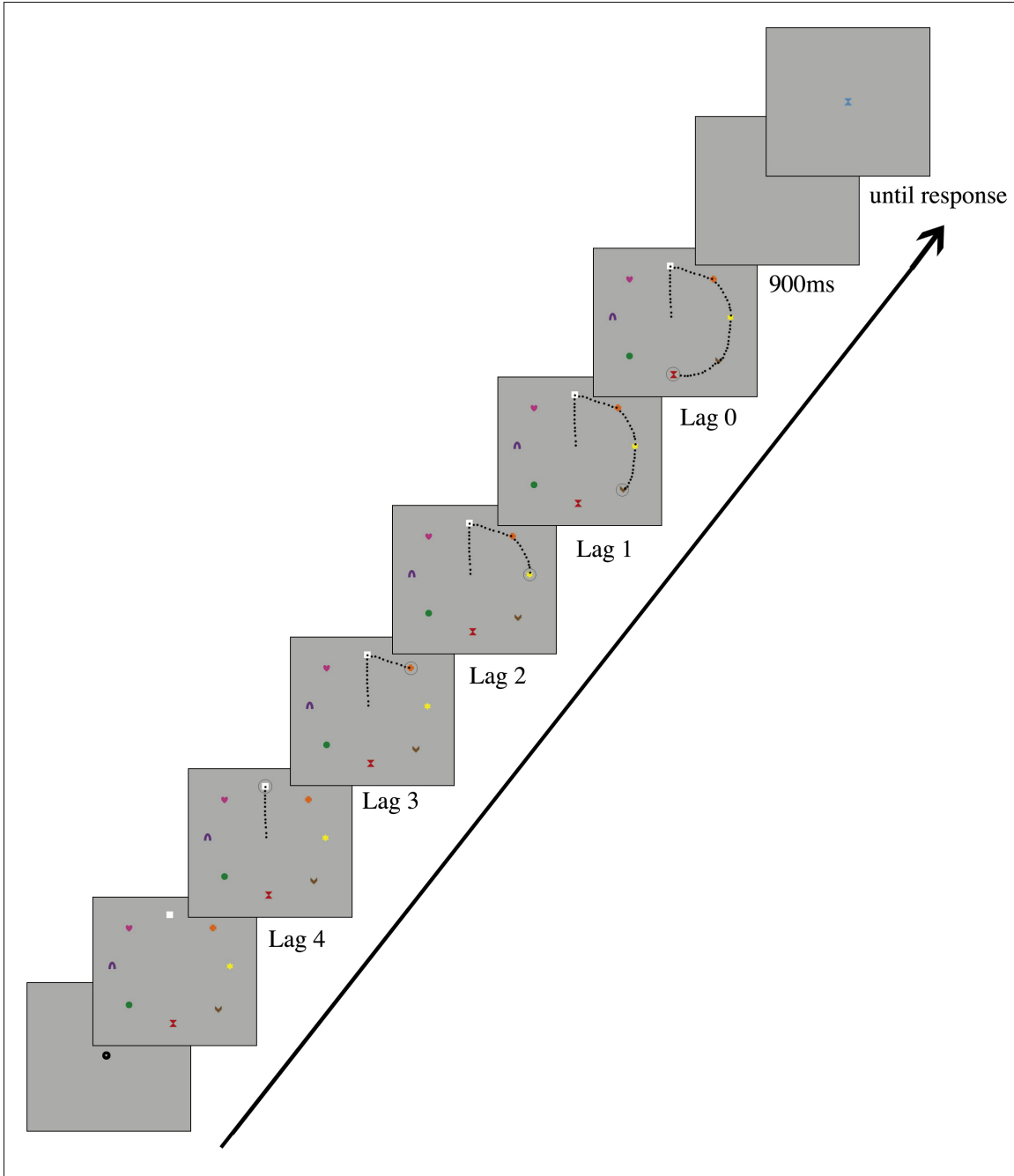


Figure 4: Procedure for Experiment 2. The dotted lines represent eye movements and each frame represents a fixation on a new object on the study array. This is an example of a lag 0 color change. The last object fixated (lag 0) is presented on the test array, and this object changed from red to blue (a color not present on the first screen).

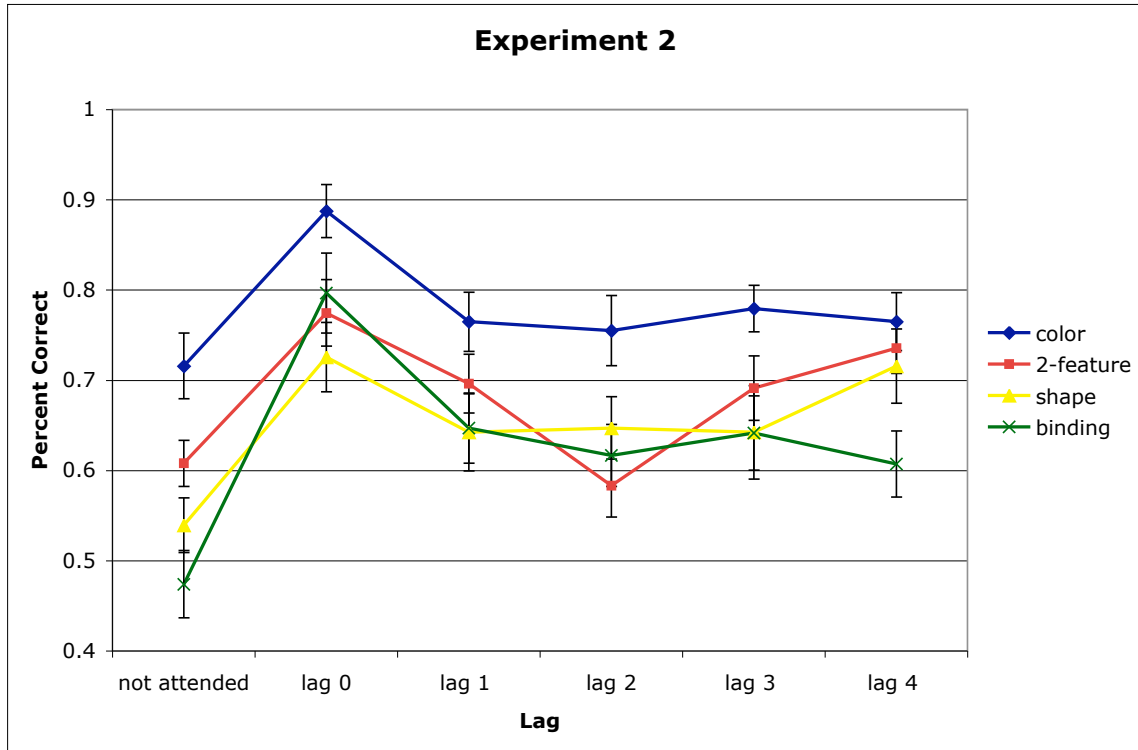


Figure 5. Results of Experiment 2. Color performance was highest, followed by the 2-feature condition, then the shape and binding conditions. Performance was highest at lag 0 for all types of changes.

Are Features and Bindings Transferred to Long-Term Memory? In order to test the hypothesis that objects at the beginning of the sequence may have been transferred to LTM, separate ANOVAs were conducted for each condition with lag (0-4) as the within subjects factor. The 2-feature ANOVA revealed a main effect of lag, $F(4, 64) = 4.55, p < .01$, partial $\eta^2 = .22$, and a significant quadratic, but not linear, trend, $F(1, 16) = 11.93, p < .01$, partial $\eta^2 = .43$, which is consistent with a primacy and recency effect. The shape ANOVA did not reveal a significant effect of lag, $F(4, 64) = 1.20, p = .32$, partial $\eta^2 = .07$, but there was a significant quadratic, $F(1, 16) = 5.17, p < .05$, partial $\eta^2 = .24$, but not linear, trend, which suggests a primacy and recency effect. In contrast, the binding ANOVA did reveal a significant effect of lag, $F(4, 64) = 4.13, p < .01$, partial $\eta^2 = .20$, and a significant linear trend, $F(1, 16) = 10.59, p < .01$, partial $\eta^2 =$

.40, which is inconsistent with a recency and primacy effect. Pairwise comparisons revealed that performance at lag 0 ($M = .80$, $SD = .18$) was significantly better than performance at all other lags, all $p < .05$, whereas performance at lag 4 ($M = .61$, $SD = .15$) did not differ from performance at lags 1 ($M = .65$, $SD = .16$), 2 ($M = .62$, $SD = .14$), or 3 ($M = .64$, $SD = .17$), indicating a recency, but no primacy, effect. This was also true of the color condition: a significant effect of lag was found, $F(4, 64) = 3.80$, $p < .01$, partial $\eta^2 = .19$, as was a significant linear (but not quadratic) trend, $F(1, 16) = 7.73$, $p < .05$, partial $\eta^2 = .33$. Pairwise comparisons revealed that performance at lag 0 ($M = .88$, $SD = .12$) was higher than performance at all other lags, all $p < .05$, while performance at lag 4 ($M = .77$, $SD = .13$) did not differ from performance at lag 1, ($M = .76$, $SD = .14$), 2, ($M = .76$, $SD = .16$), or 3 ($M = .78$, $SD = .13$). This indicates a recency, but no primacy, effect for the color condition.

Dwell time on each object was also examined to determine whether features or bindings were transferred to LTM (see Figure 6). A repeated measures ANOVA with condition (color, 2-feature, shape, binding) and lag (0, 1, 2, 3, and 4) was conducted. For lag 0, the array disappeared before the end of the fixation, so the amount of time that was spent looking at the spatial location of the object was used (that is, the amount of time looking at the object when it was on the first screen, combined with the amount of time spent looking at that spatial location during the ISI). The assumption of sphericity was violated, so a Greenhouse- Geisser correction was used. The ANOVA revealed a main effect of lag, $F(1.40, 22.47) = 9.72$, $p < .001$, partial $\eta^2 = .38$, but no main effect of condition, $F(1.95, 31.13) = 1.001$, $p = .38$, partial $\eta^2 = .06$, and no interaction, $F(4.72, 75.52) = 1.27$, $p = .29$, partial $\eta^2 = .07$. Pairwise comparisons revealed that dwell time

was greatest at lag 4 (the first object fixated; $M= 284.90$, $SD = 40.45$), and this was significantly greater than lag 3 ($M= 228.0$, $SD = 33.27$), lag 2 ($M= 203.01$, $SD = 30.55$), p and lag 1 ($M= 185.61$, $SD = 22.0$), all $p < .01$, and marginally longer than the spatial location of the object at lag 0 ($M= 200.79$, $SD = 16.51$), $p = .10$. Participants also looked longer at the object at lag 3 than the object at lag 2, $p < .05$; however, there were no differences in dwell time between lag 3 and lags 1 and 0. No other differences in dwell time were found. Therefore, participants tended to look longest at the first object, but the same amount of time for all objects after that.

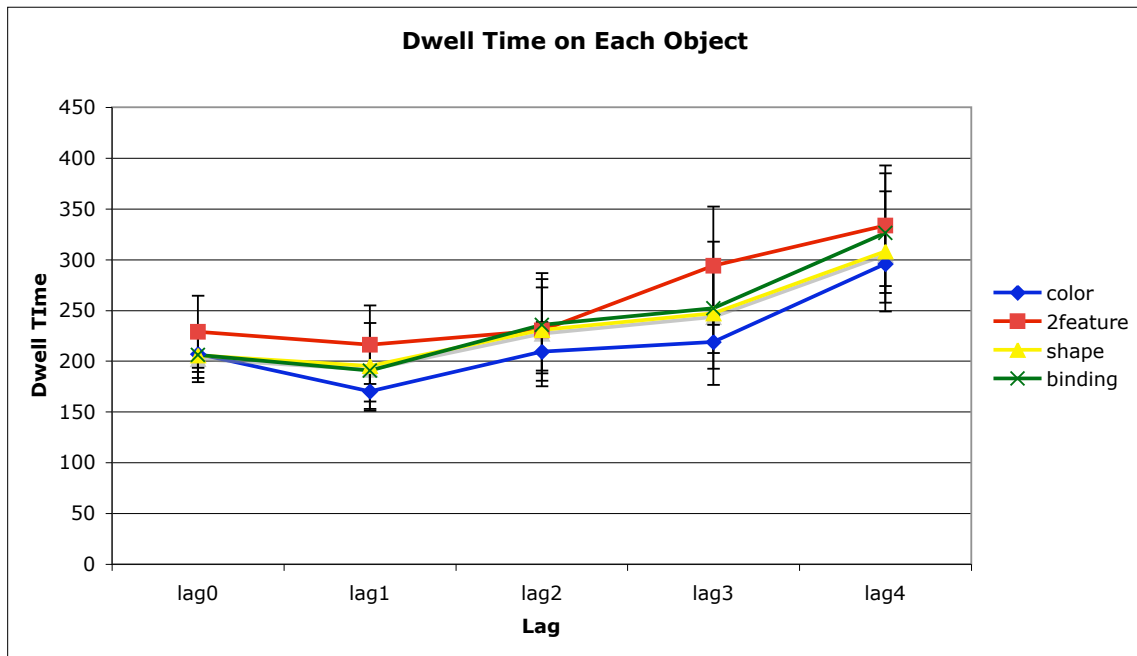


Figure 6. Dwell Time at Each Lag. There were no differences in dwell time between any conditions. Dwell time was longest at lag 4, but remained constant for each object after that.

Discussion

The results from Experiment 2 show that across all conditions, performance dropped rapidly from lag 0 to lag 1, after which performance remained steady until lag 4. This suggests that memory for both the features and bindings are best for an object that

was attended at the onset of the change. However, there was no evidence to suggest that attention is required to maintain bindings, but not individual features: there was no difference in performance between the binding and the shape (the more difficult feature) conditions. However, if attention was required to maintain feature bindings, the shifts of attention during encoding should have removed the feature bindings from previously attended items. That is, if a shift of attention is required to form a new feature binding (as in Experiment 2), old feature bindings should be lost (Wheeler & Treisman, 2002). However, this is not what occurred. Rather, feature bindings were maintained despite serial shifts of spatial location, as long as single feature information was maintained.

One alternative explanation for the results of Experiment 2 could be that attention is required to maintain feature bindings, but because the test array was a single object probe, this did not cause disruption of attention that is caused by the whole array at test (Experiment 1). However, the single object probe experiment conducted by Wheeler and Treisman (2002) did not require a shift of attention to form a new feature binding. First, only one target was presented, and it was presented in the location where participants were likely already fixating, in the center of the screen (Experiment 1 of the current study shows that participants rarely moved fixation outside of the center of the study array during encoding). The new object, therefore, should be automatically bound, requiring no shift of attention to form bindings (Treisman & Zhang, 2006). However, in Experiment 2 of the current study, serial shifts of attention occurred during encoding. It is this shifting of attention to form bindings that should remove old feature bindings (Wheeler & Treisman, 2002). Therefore, it is unlikely that using a single object probe in Experiment 2 was not attention-demanding enough to disrupt feature bindings. Rather, it appears that

some other factor is responsible for the poor binding performance found by Wheeler and Treisman (2002) and Experiment 1 of the current study.

Evidence was also found to support the hypothesis that feature bindings are not easily transferred to LTM (Logie, Brockmole, & Vandernbroucke, 2009). However, the evidence suggested that individual features were transferred to LTM. While performance in the shape and 2-feature conditions showed a primacy effect, this was not true in the binding condition, which suggests that the feature bindings were not as easily transferred to LTM as individual features. There was also no primacy effect for color; however, this may have been the result of ceiling effects. Performance for color remained high across all lags. It is possible that a long-term memory representation simply would not have yielded higher color performance. In addition, participants looked longest at the first object they looked at (lag 4) across all conditions, which could support encoding into a more long-term representation.

GENERAL DISCUSSION

The results of Experiment 1 replicate findings that have been used to propose that attention is required to maintain feature bindings: it was more difficult to detect binding changes than shape changes. However, the results from Experiment 2 support the hypothesis that attention is not required to maintain feature bindings: binding changes were detected as well as shape changes. Experiment 2, however, encouraged shifts of attention between objects and directly controlled whether a changed item was within the focus of attention. This suggests that the results from Experiment 1 reflect a difficulty in maintaining feature bindings that is not related to attention.

One possible explanation for the disparity between Experiments 1 and 2 is that the whole array response somehow disrupts the bindings for a reason other than shifts of attention. Feature bindings may not be attention demanding, but may be more fragile and susceptible to overwriting of new information (Allen, Baddeley, & Hitch, 2006; Alvarez & Thompson, 2009; Logie, Brockmole, & Vandembroucke, 2009). The whole array response screen, which contains the same number of objects as the study array, and which displays objects at test in the same locations in which objects appeared in the study array, may overwrite the binding information, but not the feature information. However, a single object response screen contains only one object, and the new bindings are in a neutral location (bindings may be more tightly bound to their spatial locations than individual features; Treisman & Zhang, 2006), which may prevent overwriting and rebinding.

Allen, Baddeley, & Hitch (2006) found that if objects were presented serially, memory for bindings at the beginning of the sequence was lower than memory for

individual features. However, memory for bindings at the last serial position was equal to individual feature performance. This supports the idea that bindings are more fragile and more easily overwritten than individual features; new bindings interfere with old bindings. However, these results were confounded by the fact that objects at the end of the sequence were in the focus of attention, while objects at the beginning of the sequence were not. Therefore, it was possible that a change in the focus of attention, and not a fragile binding representation, could have caused the loss of bindings for the first objects presented. However, the results from the Experiment 2 in the current study suggest that serial shifts of attention do not disrupt memory for feature bindings.

The difficulty in transferring feature bindings into LTM may also be the result of a fragile binding representation. Logie, Brockmole, and Vandembroucke (2009) found that repeated feature bindings could be learned, but only if the feature bindings were repeated on every trial; this is likely because feature bindings are easily overwritten by the formation of new feature bindings. In the current study, individual features appeared to be more easily transferred to LTM than feature bindings. That is, a primacy effect was found in the 2-feature and shape conditions, but not in the binding condition. This may be because the fragile nature of feature bindings requires repeated exposure before bindings are encoded into LTM.

Additional experiments are required to test the hypothesis that the whole report disrupts the fragile nature of bindings, but not attention. The methodology of Experiment 2 can be adapted to test this hypothesis. After a participant looks at the final object on the screen, a mask could be presented. If the whole report methodology disrupts feature bindings because their representation is more fragile, binding performance should be

reduced compared to single feature performance. These results, along with Experiment 2 of the current study would suggest that attention is not required to maintain feature bindings, but bindings are susceptible to overwriting and rebinding, and are represented in a more fragile state than individual features.

CONCLUSION

The current study offers support for the hypothesis that attention is not required to maintain feature bindings in VWM, but that feature bindings may be easily overwritten. Experiment 1 showed that binding memory was poorer than shape memory, while Experiment 2 did not. However, the methodology of Experiment 1 may have made it more likely that feature bindings were overwritten. This fragile nature of feature bindings could explain why memory for feature bindings has been shown in some cases to be lower than memory for individual features, and why it may be difficult to encode feature bindings into LTM.

REFERENCES

- Allen, Baddeley, & Hitch (2006). Is the binding of visual features in working memory resource-demanding? *Journal of Experimental Psychology: General*, 2, 298-313.
- Alvarez, G.A., & Cavanaugh, P. (2004). The capacity of visual short-term memory is set both by visual information load and by number of objects. *Psychological Science*, 15, 106-111.
- Alvarez, G.A., & Thompson, T.W. (2009). Overwriting and rebinding: Why feature-switch detection tasks underestimate the binding capacity of visual working memory. *Visual Cognition*, 17, 141-159.
- Bays, P.A., & Husain, M. (2008). Dynamic shifts of limited working memory resources in human vision. *Science*, 321, 851-854.
- Brady, T.F., Konkle, T., Alvarez, G.A., & Oliva, A. Visual long-term memory has a massive storage capacity for object details. *Proceedings of the National Academy of Sciences*, 105, 14325-14329.
- Eng, H.Y., Chen, D., & Jiang, Y. (2005). Visual working memory for simple and complex stimuli. *Psychonomic Bulletin & Review*, 12, 1127-1133.
- Gajewski, D.A. & Brockmole, J.R. (2006). Feature bindings endure without attention: Evidence from an explicit recall task. *Psychonomic Bulletin & Review*, 13(4), 581-587.
- Hollingworth, A. (2004). Constructing visual representations of natural scenes: The roles of short- and long- term visual memory. *Journal of Experimental Psychology: Human Perception and Performance*, 30, 519-537.
- Hayhoe, M. (2000). Vision using routines: A functional account of vision. *Visual Cognition*, 7, 43-64.
- Hyun, J., Woodman, G.F., & Luck, S.J. (2009). The role of attention in the binding of surface features to locations. *Visual Cognition*, 2009, 17, 10-24.
- Johnson, J. S., Hollingworth, A., & Luck, S. J. (2008). The role of attention in the maintenance of feature bindings in visual short-term memory. *Journal of Experimental Psychology: Human Perception and Performance*, 34(1), 41-55.
- Land, M.F., Mennie, N., & Rusted, J. (1999). The roles of vision and eye movements in the control of activities in daily living. *Perception*, 28, 1311-1328.
- Logie, R.H., Brockmole, J.R., & Vandenbroucke, A.R.E. (2009). Bound feature combinations in visual short-term memory are fragile but influence long-term learning. *Visual Cognition*, 17, 160-179.

- Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*, 279-281.
- Treisman, A.M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, *12* (97-136).
- Treisman, A., Skeys, M., & Gelade, G. (1977). Selective attention and stimulus integration. In S. Dornic (ed.), *Attention and performance VI*. Hillsdale, NJ. Lawrence Erlbaum, 333-361.
- Treisman, A.M., & Zhang, W. (2006). Location and Binding in visual working memory. *Memory & Cognition*, *34*, 1704-1719.
- Tsal, Y. & Lavie, N. (1988). Attending to color and shape: The special role of location in selective visual processing. *Perception & Psychophysics*, *44*, 15-21.
- Vogel, E.K., Woodman, G.F., & Luck, S.J. (2001). Storage of features, conjunctions, and objects in visual working memory. *Journal of Experimental Psychology: Human Perception and Performance*, *27*, 92-114.
- Wheeler, M. E., & Treisman, A. (2002). Binding in short-term visual memory. *Journal of Experimental Psychology: General*, *131*, 48-64.
- Woodman, G.F. & Vogel, E.K. (2008). Selective storage and maintenance of an object's features in visual working memory. *Psychonomic Bulletin & Review*, *15*, 223-229.

VITA

Amanda E. van Lamsweerde was born in Valencia, California, in 1984 to parents Deborah and Carl van Lamsweerde. She graduated from Mission Viejo High School in Mission Viejo, California, in 2002. In the fall of 2002, she attended the University of California, Irvine. From March 2004 to June 2005, she worked as a research assistant with Dr. Donald Hoffman. During her third year, she became a member of Psi Chi and Phi Beta Kappa. During her fourth year, she received an Undergraduate Research Opportunities Program grant and completed an honors thesis under the supervision of Dr. Emily Grossman investigating biological motion perception for artificially evolved forms. She graduated magna cum laude with honors in 2006 with a Bachelor of Arts in psychology.

In 2007, Amanda began the doctoral program in cognitive/developmental psychology at Louisiana State University under the supervision of Dr. Melissa Beck. She has presented posters of her research at the Psychonomic Society meeting in 2008 and 2009, the Women and Gender Studies Conference at Louisiana State University in 2008, the Life Course and Aging Poster Session at Louisiana State University in 2008 and 2009, and at the Vision Sciences Society meeting in 2010.