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What you attend to is what you remember : investigating the unit of representation in visual working memory

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WHAT YOU ATTEND TO IS WHAT YOU REMEMBER: INVESTIGATING THE UNIT OF REPRESENTATION IN VISUAL WORKING MEMORY

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For Mom and Dad

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ABSTRACT

The unit of representation in visual working memory (VWM) is a matter of some debate. The object benefit occurs when more features are remembered when they are combined into fewer objects. This has been used to support the perspective that objects are the unit of representation in VWM. However, the object benefit occurs only for two features from different dimensions (e.g., a blue circle: color and shape) but not two features from the same dimension (e.g., a red-and-blue bi-colored square: two colors). This suggests that both objects and features may be important in determining VWM capacity. The purpose of this study was to compare the object hypothesis against a new, alternative unit of representation: the Boolean map. A Boolean map is a spatial representation that can also carry information about features, although feature tags must be applied to an entire map. The Boolean map distinguishes between features that must be accessed serially and features that can be accessed in parallel: features that can be accessed in parallel can be represented on the same map, while features that are accessed serially must be represented on different maps. Three experiments were conducted to explore both hypotheses. In Experiment 1, the hypothesis that some types of stimuli are not attended as objects was examined by testing object-based attention for different kinds of objects. In Experiment 2, the Boolean map hypothesis was tested by examining which features can be accessed in parallel and which features must be accessed serially. Finally, in Experiment 3, the object benefit in VWM was tested for the same stimuli used in Experiments 1 and 2. The results showed that even objects that did not show an object benefit in VWM in Experiment 3 were still attended as objects in Experiment 1. However, only features that could be attended in parallel when combined into an object

(Experiment 2) showed an object benefit in VWM (Experiment 3). These results suggesting that the unit of representation is restricted by the features that can be accessed in parallel, in support of the Boolean map hypothesis.

CHAPTER 1. INTRODUCTION

1.1 Visual Working Memory

The visual world is in constant flux. People and objects move, change features, become occluded, and disappear from view. Interacting with this dynamic environment requires the recruitment of a robust, capacity- and time-limited memory system referred to as visual working memory (VWM). Visual working memory is defined by its limited capacity (three to four items; Alvarez & Cavanaugh, 2004; Luck & Vogel, 1997), its short duration (several seconds; Zhang & Luck, 2009), and the ease with which one can access its contents (Landman, Spekreijse, & Lamme, 2003). This is in contrast to visual long-term memory, which can store an apparent infinite amount of information (Brady, Konkle, Alvarez, & Oliva, 2008; Standing, 1973), can last for years (Bahrick, Bahrick, & Wittlinger, 1975), but can be more difficult to retrieve information from without cues (Beck & van Lamsweerde, 2011). Visual working memory is needed for many daily tasks, from tasks that seem effortless, such as making accurate eye movements (Hollingworth, Richard, & Luck, 2008) or looking for a red shirt in a closet (Carlisle, & Woodman, 2011), to more demanding tasks, such as tracking moving objects (e.g., players on a football field; Makovski & Jiang, 2009) or preventing multiple searches through the same locations and objects, as when searching for a set of keys on a crowded desk (Peterson et al., 2001). VWM is also used to detect changes in the environment. As information changes from one view of the world to the next, information about the previous views must be maintained in VWM for the change to be noticed.

To illustrate the need for VWM to detect changes in an everyday task imagine driving a car. In order to effectively (and safely) navigate traffic, several different areas must be attended. In addition to monitoring the cars in front you, the rearview and side mirrors must be checked to determine if you are a safe distance from all vehicles. When making a lane change, you must look in your mirrors and over your shoulder and then look to the road in front of you. However, in a driving environment, the other cars on the road (as well as motorcyclists, bicyclists, and pedestrians) are also constantly moving. If, while looking over your shoulder, the car in the lane to your right moved directly in front of you - so now there is a different car immediately in front – will you notice this change? If you do notice the change (*change detection*), it may seem immediate and effortless. However, detecting the change actually requires several steps. First, the car ahead of you must be attended and stored in VWM prior to looking over your shoulder (Simons & Rensink, 2005). Then, when you look back to the road ahead after looking over your shoulder, the representation of the old car (in VWM) must be accurately retrieved and compared to the new car in front of you (Hollingworth, 2003). A failure at any of these stages will result in a failure to notice the change (*change blindness*). This study will focus specifically on one stage of this process: the storage of the item in VWM.

Only a small number of items can be stored in VWM (three to four; Luck & Vogel, 1997) and VWM is limited in duration (Zhang & Luck, 2009); therefore, strategic use of VWM depends on storing the objects or features that are most likely to change (Beck, Angelone, & Levin, 2004; van Lamsweerde & Beck, 2011). For example, it would be important to remember the color of car in front of you, but less important to remember the color of your passenger's shirt. The ability to strategically use VWM in this way is limited by how the information is stored in VWM. Therefore, in order to understand the functions of VWM for everyday tasks (e.g., guiding search, detecting changes, maintaining a stable representation across eye movements), it is important to understand the structural limitations of VWM memory, such as: what is stored, how many things are stored, and how long do representations last?

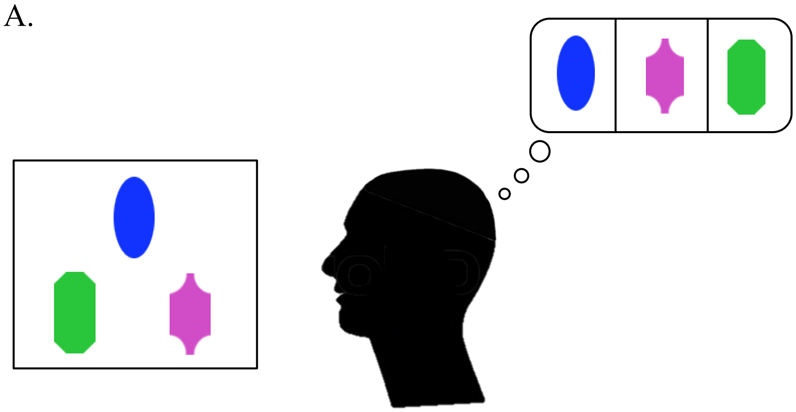
The purpose of this project is to determine the unit of storage in VWM. There are two overarching perspectives: objects and features (although the climate regarding this topic is rapidly changing; Brady, Konkle, & Alvarez, 2011; Brady & Tenenbaum, 2012). This study explores both the traditional perspectives regarding the unit of representation in VWM as well as a new alternative that may be better able to explain a divided body of research.

First, 'features' and 'objects' are defined. Visual information can be separated into several separable dimensions, such as color, orientation, texture, shape, size, etc; values along these dimensions (green, red, circle, square, etc.) are features (Treisman & Gelade, 1980). Although there are many cues that may indicate that a collection of features may be part of a single 'object,' for the purposes of this study, an object is defined by one of two qualities (Palmer & Rock, 1994). First, multiple features that share a single boundary and uniform surface feature are perceived as being a single object. For example, a 'green circle' contains a single color that completely fills the circle's boundaries. Second, two features that are connected to each other are objects. For example, a blue square on top of a red square is a single 'object' (with two parts). In contrast, a red square and a blue square that are not connected are two objects. Therefore, in this study, *objects* are any stimuli that contain one of these two qualities.

1.2 The Unit of Representation in Visual Working Memory

There are two umbrella views regarding the unit of storage in VWM. The first and dominant view is that VWM stores objects: all features of an object are stored together (see Figure 1, letter A). The object perspective often also implies that multiple features can be remembered per object with little to no cost to the number of objects that can be stored (Awh, Barton, & Vogel, 2007; Fukuda, Awh, & Vogel, 2010; Luck & Vogel, 1997; Vogel, Hollingworth, & Luck, 2001, but see Alvarez & Cavanaugh, 2008) or the quality of the representations (Anderson, Vogel, & Awh, 2011; Zhang & Luck, 2008; but see Bays & Husain, 2008). For example, most cars are painted a single, solid color. However, Mini Coopers may have a roof and mirrors of a contrasting color (generally either black or white). According to the object hypothesis, the representation of a red-and-white Mini Cooper would contain the information about shape and the colors all bound together in a unified representation. This representation should consume no more capacity than an all-red Mini Cooper. The implication from the object-based framework is that the limit to VWM capacity is the number of objects that need to be stored, not the number of features to be remembered per object (Luck & Vogel, 1997).

A.



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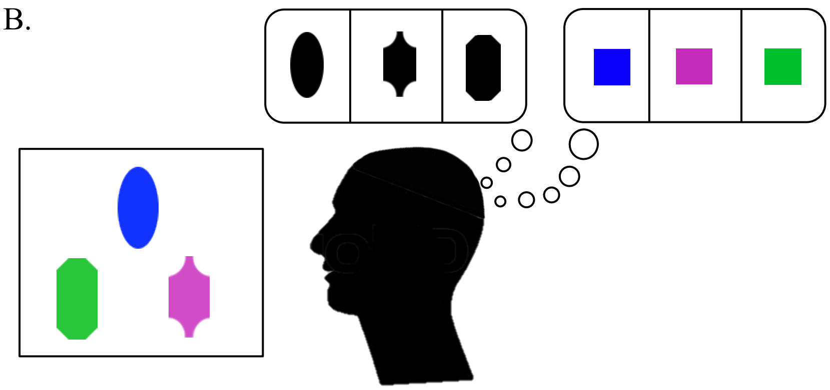


Figure 1. Object and feature representations. This figure illustrates how a person may remember the three objects in the sample array from an object-based (A) or feature-based (B) perspective. Note that in both examples it is easy for the person to remember all six features (three colors and three shapes) of the three objects.

In contrast, the feature hypothesis posits that individual features are stored in VWM (Wheeler & Treisman, 2002; see Figure 1, letter B). According to this perspective, the features of an object are not stored together as unified objects (unless attention is recruited: Brown & Brockmole, 2010; Fougnie & Marois, 2009; Wheeler & Treisman, 2002). Rather, the features of an object are stored separately, in dimension-specific stores. Therefore, the representation of the shape of a Mini Cooper is stored separately from the representation of the colors. The 'red' and 'white' are stored in a color dimension store, while the shape is kept in a separate shape dimension store. This perspective suggests that the two colors of the Mini Cooper will compete with each other for capacity, but they will not compete with the shape of the car for capacity.

Compelling research in favor of the object perspective comes from Luck and Vogel (1997), who found that memory performance when participants were required to remember up to four features of an object (color, orientation, gap presence or absence, and size) was the same as when participants were required to remember only a single feature (e.g., color). Luck and Vogel utilized a change detection task as an index of what information (and how much) was stored in VWM. In a change detection task, participants view an array of objects (generally anywhere from 100ms to 1000ms), followed by a blank screen ISI, then a test array of objects (see Figure 2). The participants then determine if any of the objects changed from the study array to the test array by responding 'yes' or 'no.' In order to accurately detect a change, the participant must remember the features of the object that changed. For example, in order to determine that a color change occurred, the participant must remember the color of the changing object from the study array. Because VWM capacity is limited, performance decreases as the amount of information to be remembered increases. The researcher can manipulate how many objects are present in an array (the set size), the number and type of features each object is composed of, and the types of changes that might occur (e.g., color changes or orientation changes, or both, etc.).

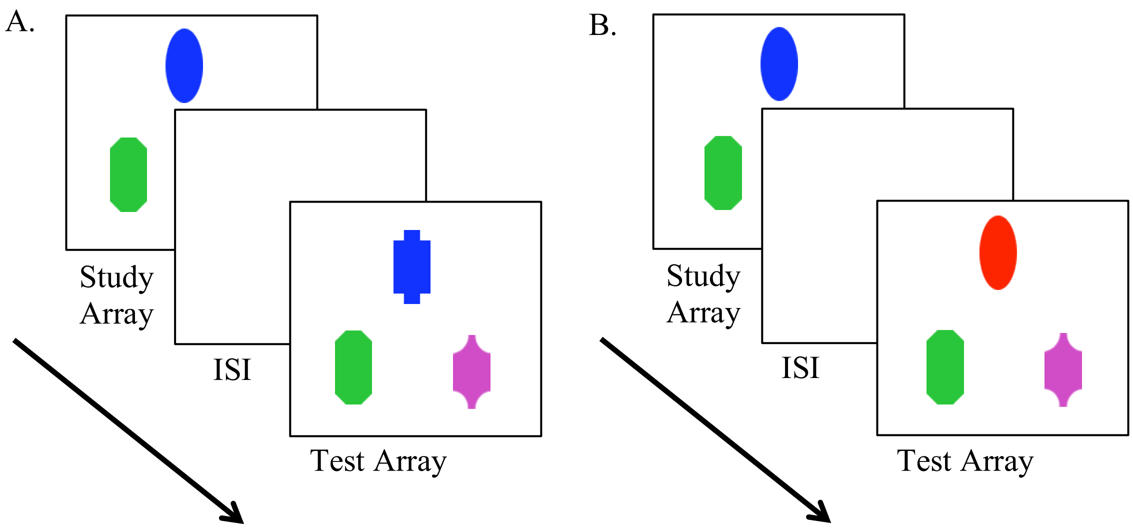


Figure 2. Examples of a change detection task. Participants view an array of objects for a short period of time (usually between 150 – 900ms), followed by a blank screen interstimulus interval (ISI), then a test array of objects. A shows an example of a shape change and B shows an example of a color change. Usually, half the trials are change trials and half are no-change trials; participants indicate whether a change occurred (yes or no).

The results of Luck and Vogel (1997) showed that, regardless of whether participants were required to only remember a single feature of the study objects (e.g., only color changes could occur, making only color relevant), or whether they were required to remember all four features (e.g., color, orientation, size, and gap changes could all occur), change detection performance was the same. This suggested that once an object was stored in VWM, all of its features could be stored ‘for free’ (the *features-for-free effect*). However, change detection performance did decrease as the set size (the number of objects displayed) increased. This provided striking (and frequently cited) evidence that VWM stores objects because multi-featured objects apparently consumed as much capacity as single featured objects. These particular results have been replicated with orientation and size (Olson & Jiang, 2002), color and orientation, and color and shape (Luria & Vogel, 2011).

However, the features-for-free effect described can be explained by the feature hypothesis, because all features of the objects were from different dimensions (Wheeler & Treisman, 2002). According to the feature hypothesis, each feature dimension has a separate store and a separate capacity limit in VWM, so the features do not compete with each other for capacity. Therefore, it is possible that the features-for-free effect is not the result of object-based representations in VWM.

To test this possibility, Luck and Vogel (1997) included an experiment in which participants detected changes to bi-colored squares (an inner square surrounded by an outer square of a different color). According to the feature hypothesis, because both features of a bi-colored square are from the same feature dimension, performance for bi-colored squares should be lower when participants had to remember both colors of the square, compared to when they only had to remember one color. However, participants were able to remember both colors of the bi-colored squares as well as only a single color. The presence of a features-for-free effect with bi-colored squares is important because it is evidence against a feature-based unit of representation.

However, these bi-colored square results have generally not been supported by subsequent research (Olson & Jiang, 2002; Wheeler & Treisman, 2002; Xu, 2002). With few exceptions (Vogel, Hollingworth, & Luck, 2001), subsequent research has shown that performance for bi-colored objects is lower than performance for single colored objects (Olson & Jiang, 2002; Wheeler & Treisman, 2002). Wheeler and Treisman (2002) found that, regardless of how the two colors were arranged within a bi-colored square (e.g., one square inside the other, one square split in half, etc.), performance was better for three individually colored squares than for three bi-colored squares. The bi-colored square results, then, are somewhat ambiguous with regard to which hypothesis (object or feature) is supported.

In addition, it is possible that representations are object-based, but that all features of the object are not necessarily represented for free. For example, more visually complex objects, or object composed of multiple parts, consume more capacity than simple objects (Alvarez & Cavanaugh, 2004; Davis & Holmes, 2005; Eng, Chen, & Jiang, 2005; Fougnie, Apslund, & Marois, 2010; Gao et al., 2009; Xu, 2002a). This research suggests that if the unit of representation in VWM is object based, the capacity per object may be variable. Therefore, it is possible that objects may form the unit of representation, even if additional features are not stored without cost. To account for this possibility, additional support for the object hypothesis comes from the *object benefit.* While the features-for-free effect typically results from manipulating the number of features per object, an alternate approach is to keep the number of features to be remembered constant, but vary the number of *objects.* With this method, evidence suggests that more features can be remembered when there are fewer objects used to represent them (Delvenne & Bruyer, 2004; Xu, 2002). This is known as the *object benefit* and provides more evidence in favor of the object hypothesis, as it cannot be easily explained by the feature hypothesis.

1.3 The Object Benefit

The object benefit emerges when more features can be remembered (Figure 3) when they are combined into fewer objects (e.g., a blue circle) than if the features are separated, into multiple objects (e.g., two objects, one that is blue, and one that is a circle; Delvenne & Bruyer, 2004; Olson & Jiang, 2002; Xu, 2002b). Delvenne and Bruyer (2004), for example, had participants detect shape or texture changes. In one condition, black random polygons were placed on top of textured squares. The resulting stimuli resembled two objects: one on top of the other. Participants were required to detect either texture changes (to the squares) or shape changes (to the polygons). In a second condition, the random polygons were filled with the texture, such that both features were part of a single, unified object. Performance was higher when the two features (shape and texture) were combined into a unified object (fewer objects), even though the participants needed to remember the same total number of features to complete the task in both conditions. These results have been replicated with other dimensions, including shape and color (Luria & Vogel, 2011), color and orientation (Xu, 2002), and orientation and size (Olson & Jiang, 2002). The object benefit has been interpreted to mean that VWM stores objects (Luria & Vogel, 2011). Figure 3 shows an example of how change detection performance can be affected by incorporating multiple features into unified objects. According to the object hypothesis, the capacity limit to VWM is on the number of objects; therefore, combining two features into a single object reduces the total amount of resources consumed by those two features. This increases change detection performance, as it is more likely that the changing feature will be remembered.

Event-related potential (ERP) results have also supported the object hypothesis. Contralateral delay activity (CDA) is an ERP component that is sensitive to the number of objects stored in VWM (Ikkai, McCollough, & Vogel, 2010; Luria, et al., 2009; McCollough, Machizawa, & Vogel, 2007; Vogel, McCollough, & Machizawa, 2005). The CDA amplitude increases as set size increases, but asymptotes once capacity limits are reached. CDA is sensitive to individual differences in VWM capacity (Vogel & Machizawa, 2004; Vogel et al., 2005). For example, for an individual with a capacity limit of three items, CDA amplitude will increase

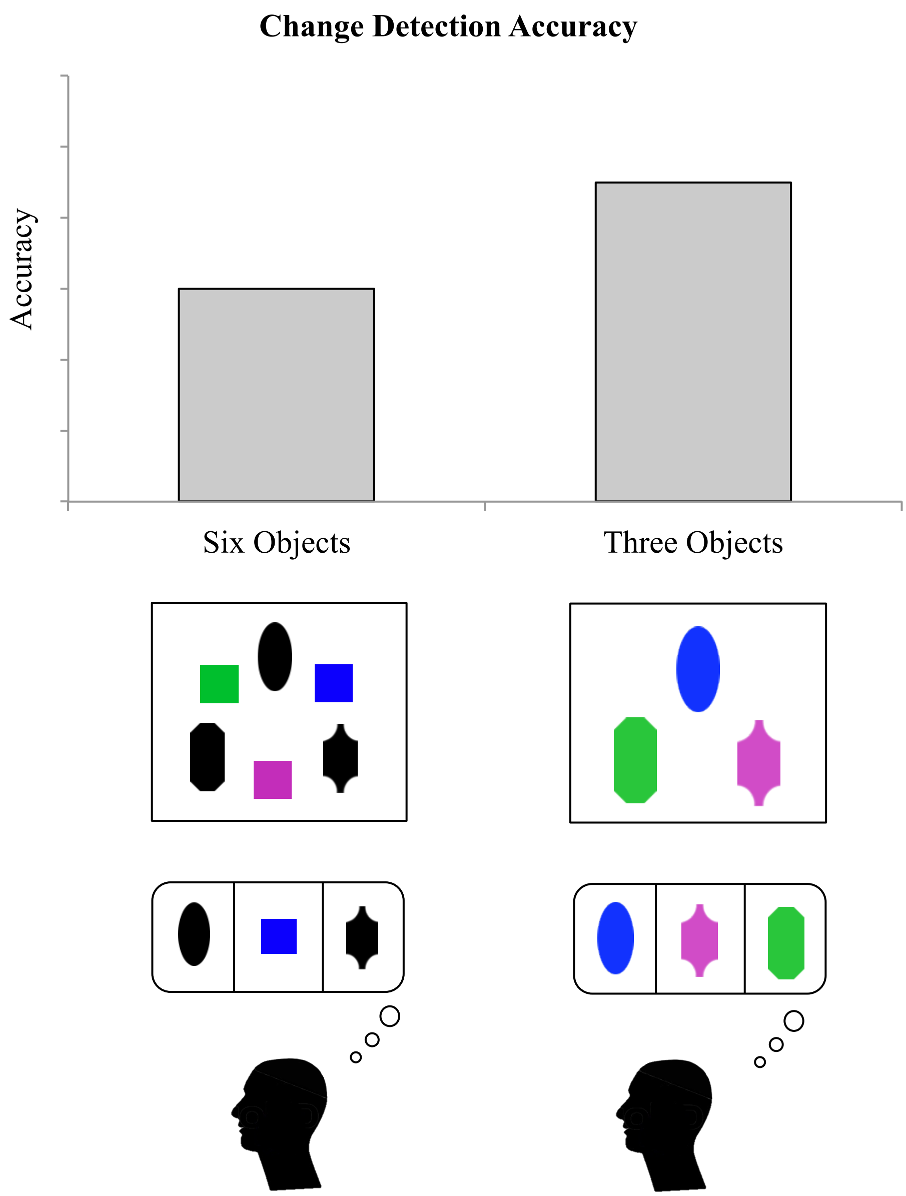


Figure 3. The object benefit. This figure illustrates the object benefit in memory as well as the object hypothesis. Performance is better in the three-object condition than the six-object condition, even though the change detection tasks requires remembering three colors and three shapes in both conditions. This is generally interpreted to mean that objects are the unit of representation in VWM. Because both features of an object are stored together, all six features can be remembered when there are three objects, but only three features can be remembered when there are six objects.

from set sizes one to three, but will not increase from set size three to four. The authors of research using the CDA say this occurs because, even though there are more objects present with set size four, only three objects are represented in VWM (Vogel & Machizawa, 2004).

Luria and Vogel (2011) showed participants several different types of stimuli during a change detection task while monitoring CDA. In one condition, participants saw a black polygon and detected shape changes to the polygon (*single feature condition*; one object, one feature). In a second condition, participants saw a polygon filled with color and were told to detect either color or shape changes (*conjunction condition*; two features, one object). In a third condition, they saw a black random polygon and a colored square and were told to detect shape changes to the polygon and color changes to the square (*disjunction condition*; two colors, two objects). CDA amplitude was equal for the single feature and conjunction conditions (same number of objects), but was greater in the disjunction condition (more objects). This suggests that there is no capacity cost to adding a feature to an object, but there is a cost to adding an object. These results were mirrored in the behavioral data: change detection accuracy was equal in the single feature and conjunction conditions, which were better than change detection performance in the disjunction condition. These results were also replicated with colored, oriented bars where participants detected orientation changes instead of shape changes (Luria & Vogel, 2011).

Although there is a lot of data supporting the object hypothesis, there is one important effect that is not adequately explained. Specifically, there is typically no object benefit when an object contains two features from the same dimension (see Figure 4, Olson & Jaing, 2002; Xu, 2002b; Wheeler & Treisman, 2002). The object hypothesis cannot explain why the object benefit only arises when both features of an object come from the same dimension. For example, Xu (2002b) used mushroom-like stimuli that consisted of a 'cap' and a 'stem.' In one experiment, the caps were different colors and the stems were different orientations. The caps and stems were combined to form a single object (conjunction condition), or they were separated into two separate objects (disjunction condition). Performance was higher in the conjunction condition than the disjunction condition, even though the total number of features that had to be remembered was the same in both conditions. However, in a second experiment, the 'stems' were colored, instead of oriented, such that when the caps and stems were combined, they formed bi-colored stimuli. In this case, there was no object benefit: performance was the same when the caps and stems were separated as when they were combined. Similarly, Wheeler and Treisman (2002) found that performance for six single colored squares was equal to three bi-colored squares.

In addition, behavioral and ERP results regarding the object benefit for two colors are somewhat at odds. As described above, Luria and Vogel (2011) found that for two features from different dimensions, increasing the number of objects to remember, but not the number of features per object resulted in an increase in CDA. However, they ran a second experiment where participants detected only color changes. Participants detected changes to: 1) a single colored square (single feature condition), 2) a bi-colored square (conjunction condition), or 3) two single colored squares (disjunction condition). The CDA amplitude was greater in the conjunction condition than in the single feature condition. This differed from the results of the first experiment, which showed that CDA amplitude for a conjunction of color and shape was equal to a single featured object. However, CDA amplitude was also greater in the disjunction condition than the conjunction condition. These results suggest that with colors, there is both a cost to adding features to an object and a cost to remembering multiple objects. The behavioral

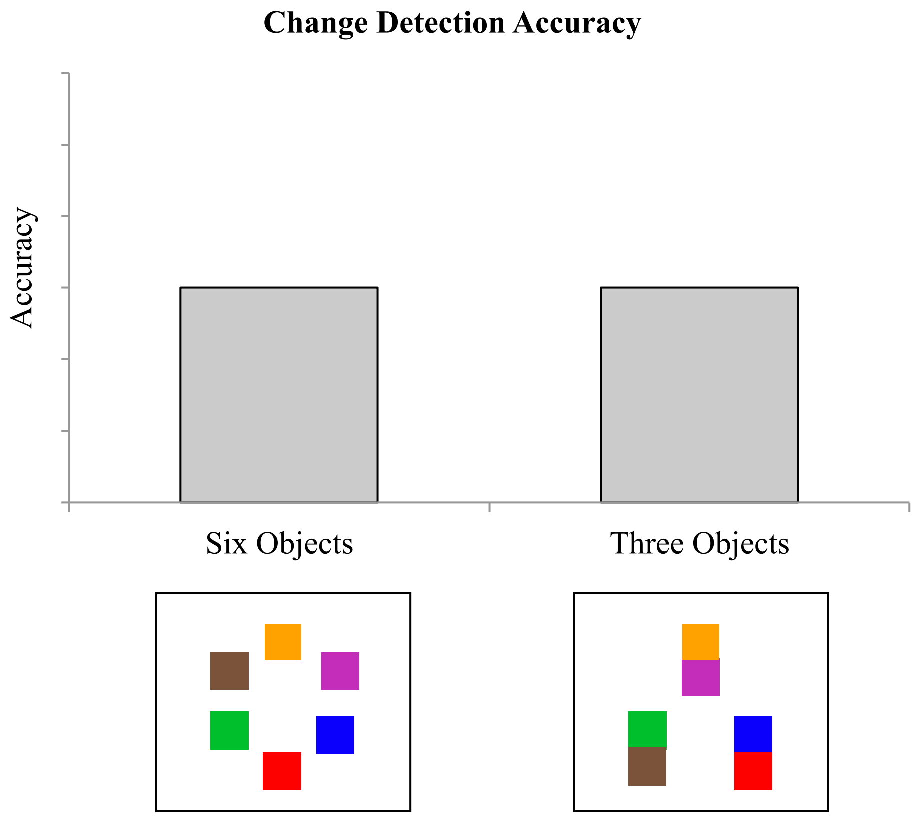


Figure 4. No object benefit for two colors. When objects are composed of two colors, an object benefit is usually not found. Here, accuracy is the same regardless of whether there were six objects or three objects.

data, however, did not follow the exact pattern of results as the CDA data and did not replicate Luck and Vogel (1997). The behavioral data revealed that change detection performance was better in the single feature condition than the conjunction condition (similar to the CDA activity). However, there was no difference in performance between the disjunction and conjunction conditions (unlike the CDA data). The behavioral data suggests that a single bi-colored square consumes the same amount of capacity as two single colored squares, while the CDA data suggest that one bi-colored square consumes less capacity than two single colored squares. The authors explain this discrepancy by pointing out that change detection relies on several processes besides just storage (e.g., making a correct decision), and that CDA is a better measure of the number of objects actually stored in VWM. Regardless, Luck and Vogel's (1997) behavioral results in support of object based representations were not replicated.

The sum of the research on the object benefit highlights two important sets of results. First, when two features from different dimensions are combined into a single object, more features can be remembered (the object benefit). Second, this benefit is restricted to features from different dimensions, and does not usually extend to features from the same dimension. Olson and Jiang (2002) referred to this pattern as the weak object benefit, suggesting that two features from the same dimension cannot benefit from being incorporated into a single object. Previous research has predominately used color to investigate how two features from the same dimension may be combined into an object (e.g., bi-colored squares). While there is less research investigating this question, Kim and Kim (2011) found that two shapes could be combined into a unified object to produce an object benefit. This suggests that the object benefit can occur for two shape features, and the lack of an object benefit when two features come from the same dimensions is specific to color. However, it is unclear why shape and color would differ in their abilities to produce an object benefit.

It is possible that the object benefit is not necessarily evidence in support of object-based representations. Fougnie and Alvarez (2011) found that the likelihood of remembering one feature of an object (e.g., color) is independent from the likelihood of remembering another feature of the object (e.g., orientation). This is inconsistent with the hypothesis that all features of an object are stored together, as a bound representation. Furthermore, the cost (in VWM accuracy) that is created by adding multiple objects to a memory display may differ from the cost that is created by adding features to an object (Fougie et al., 2010). This suggests that the object benefit may not necessarily indicate that the object serves as the unit of representation in VWM.

However, the number of objects to be remembered clearly impacts memory performance, indicating that a strict feature-based unit of representation in VWM is not viable. The data suggest that both the number of objects and the number (and type) of features are important in determining how information is remembered in VWM. Together, this suggests that the unit of representation in VWM may not be strictly object or feature based, but rather may be a different unit that combines elements of both (Baddeley, Allen, & Hitch, 2011; Brady, Konkle, & Alvarez, 2011; Fougnie, Apslund, & Marois, 2010).

The current study tested two hypothesized units of representation: the object and the Boolean map. The object hypothesis proposes that objects serve as the unit of representation in VWM. The object hypothesis is contradicted by the findings that the object benefit does not generally exist for objects composed of two features from the same dimension (i.e., bi-colored squares). However, it is possible that bi-colored objects do not show an object benefit in VWM because these stimuli are not perceived or attended as objects by the viewer. For example, in Delvenne and Bruyer (2004), the random polygons on top of textured squares were likely perceived as two objects, while in Luck and Vogel (1997), it was assumed that the bi-colored square (an inner colored square surrounded by an outer colored square) was perceived as a single object. It is possible that, despite the presence of perceptual cues such as proximity or connectedness, some stimuli are not perceived or attended as objects (especially objects that do not share a uniform surface feature), and there is therefore no benefit to combining two features into a single object (as defined by connection between the features). Therefore, the object hypothesis of VWM was tested by determining whether object-based attention operates on bi-colored stimuli, as well as bi-shape stimuli and colored shapes. In addition, this study investigated a new framework for conceptualizing the unit of representation in VWM: the

Boolean map. This is a proposed unit of representation in attention that emphasizes the importance of both features and objects. The next two sections discuss: 1) how object-based attention operates and how it may serve to support the object hypothesis in VWM and 2) what a Boolean map is, and how it may serve as the unit of representation in VWM.

1.4 What is an Object? Object-Based Attention

The conflicting evidence in support of the *object hypothesis* may be explained if certain stimuli are not attended as objects. While the concept of attention has proved notoriously difficult to adequately define (Scholl, 2001), it most commonly defined as a mechanism of selection that allows the observer to choose a small set of information to process, while excluding distracting information, out of the vast amount of information that is readily available (Marino & Scholl, 2005). In the visual domain, there is some debate over the unit of attention (as with VWM): that is, *what* gets selected? Early theories of attention focused on the spatial nature of attention, utilizing analogies of a spotlight or zoom lens (Eriksen & St. James, 1986; Posner, Snyder, & Davidson, 1980). According to a purely spatial account, attention gets distributed evenly across space. Whatever information falls within the spotlight (for example) has priority for processing. However, space-based accounts of attention are incomplete, as attention has also been shown to operate selectively over objects (Egly, Driver, & Rafal, 1994; Marino & Scholl, 2005).

Evidence for object-based attention is found when participants are faster at identifying a target that appears on an attended object than on an unattended object. For example, Egly et al. (1994) presented participants with two rectangles (see Figure 5). One end of one of the rectangles was briefly cued (this cue served to orient attention to the cued location). Then, a target appeared in one of three locations: 1) in the cued location (valid trials), 2) in the opposite end of the cued object (invalid, within object trials), or 3) in the end of the uncued object (invalid, between object trials). Importantly, the target distance from the cued location was the same for both invalid within object trials and invalid between object trials. Because the cue draws attention, participants should be fastest to respond if the target appears in the cued location (which they are). Then, the cost in reaction time (RT) to a target appearing in a non-cued location can be measured as the difference in RT when the target appears in a non-cued location compared to when the target appears in the cued location. The within-object cost and the between-object cost can then be directly compared. According to a purely space-based account, the within-object cost and between object cost should be identical because the distance from both non-cued locations to the cued location is the same. However, the results showed that the between-object cost was greater than the within-object cost. This suggests that once attention was drawn to one end of an object, attention spread automatically across the object, but not equally in space. When a target appeared in the uncued object, attention had to shift away from the cued object, resulting in a slower reaction time.

Relating this concept of object-based attention back to VWM, it is possible that some stimuli (i.e., bi-colored objects) do not show an object benefit in VWM because they are not attended as objects. That is, even though two colors are connected in bi-colored stimuli (this connection serves as a perceptual cue that the two colors are part of a single object), the lack of a uniform surface feature (Palmer & Rock, 1994) may prevent these stimuli from being attended as an object. The possibility that some object-like stimuli are not attended as objects is supported by research that demonstrates that some perceptual cues can limit the object-based spread of

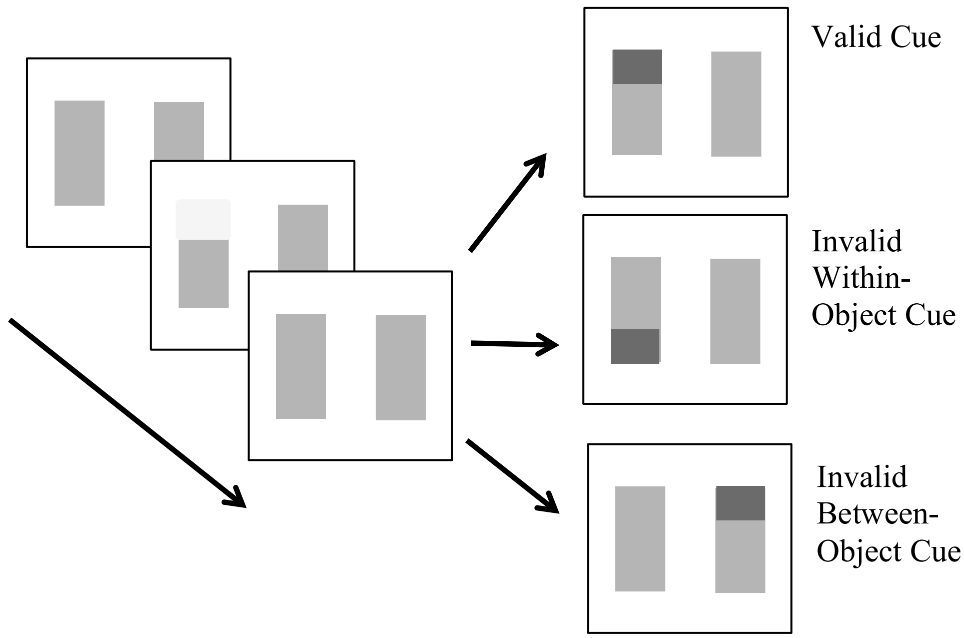


Figure 5. Object-based attention task. Participants are cued to one end of an object (the lightened square) followed by a target (the darkened square). Participants respond to the target as quickly as possible. Evidence for object based attention is found when participants are faster to respond to a target that appears in the same object as the cue (within-object invalid trials) than when the target appears in the uncued object (between-object invalid trials).

attention. Specifically, objects that have heterogeneous surface features (e.g., two different colors) may not be subject to the automatic object-based spread of attention (Hecht & Vecera, 2007; Matsukura & Vecera, 2006; Watson & Kramer, 1999. Hecht and Vecera (2007) had participants respond to targets in rectangles (these were empty rectangles defined by a border); the border was either a single color, or two different colors (one color on top of a second color). They found that responses were faster to target that appeared within the cued object, but only for objects with a single-colored border. Similarly, in Watson & Kramer (1999), participants searched for two different targets on wrench-like stimuli. When the targets were on either end of the same object, participants were faster to respond than if the targets appeared on ends of two different objects. However, when the center of the wrench was covered in a pattern that split both ends of the wrench into different 'sections,' the object advantage disappeared. These results suggest that disruption of a continuous surface feature (such as color) can disrupt object-based processing (unless additional cues are present to indicate that the two colors are part of a single object: Hecht &Vecera, 2007; Matsukura & Vecera, 2006).

These results parallel the object benefit results in that bi-colored stimuli are subject to disruptions of object-based attention and they also do not show an object benefit in VWM. The comparison between object-based attention and VWM representations offers a potential object-based explanation for why bi-colored squares do not show an object benefit in VWM. The bi-color stimuli used in previous research (Luck & Vogel, 1997; Wheeler & Treisman, 2002; Xu, 2002b) necessarily have boundary lines between the squares, which may be sufficient to disrupt object-based processing. If there are no other cues to indicate that the two colors belong to the same object, bi-colored stimuli may not be selected as objects by the viewer. Therefore, the object benefit in VWM would not exist because bi-colored objects are not attended as objects. This hypothesis was tested in the current study by comparing tests of object-based attention for objects that traditionally do show an object benefit in VWM (colored shapes) to objects that traditionally do not show an object benefit in VWM (bi-colored squares). If attention can automatically spread across the object, this indicates that participants are able to identify the stimulus as an object, rather than two separate objects. According to the object hypothesis, only objects that show an automatic spread of attention will show an object benefit in VWM.

1.5 Boolean Maps

The second hypothesis tested in the current study was the Boolean map serves as the unit of representation in VWM. A Boolean map is a proposed unit of attentional access (Huang & Pashler, 2007; Huang, 2010). According to the Boolean map theory (Huang, 2010), access is a process that is distinct from that of selection (as described in the object-based attention section).

Access is the information that observer can be consciously aware of at a time, while *selection* is the process that is used to ignore distractors. For the purpose of this study, the term *attention* is used as it most commonly is used in the literature to describe the process of selection, while *access* is used to describe the information that viewers can be aware of at a given time (although the purpose of this study is not to make any claims about conscious awareness).

A Boolean map is a representation that locates individual stimuli in a spatial representation (or *map*; see Figure 6). Central to the Boolean map hypothesis is the claim that some types of information can be accessed in parallel, while other types of information must be accessed serially. This is important because individual maps are created serially; any information that can be accessed in parallel is represented on the same map, whereas information that is accessed serially is represented on separate maps.

According to the Boolean map theory, only a single feature value *per dimension* can be represented on a single map (see Figure 6). For example, each color of a bi-colored square must be accessed serially, and are therefore represented on separate maps. However, two identical features (e.g., two red squares) can be accessed in parallel and can be represented on the same map. Consequently, two identical feature values can be represented on the same map, even if these feature values are part of *different* objects.

Evidence for the premise that two different feature values are accessed serially comes from a task in which participants rapidly (~20-60 ms) viewed two study features that were different from each other (Huang & Pashler; see Figure 7). The two colors were presented either simultaneously (both colors were presented on screen together) or sequentially (one immediately after the other). Then, participants viewed a test color and determined whether it matched one of the study colors. The idea is that, if both features must be accessed one at a time (serially), then

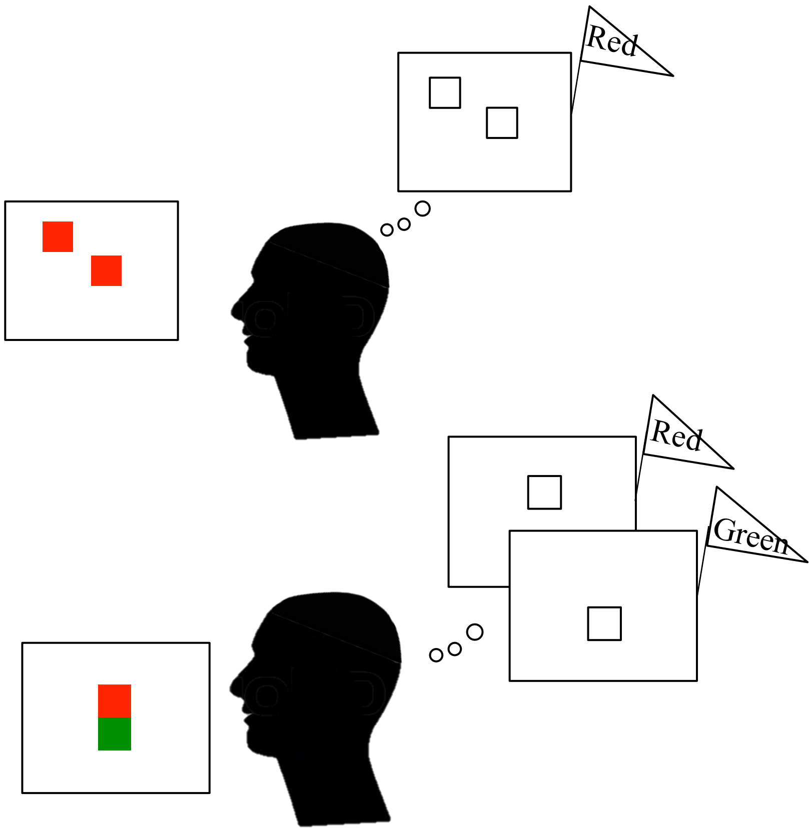


Figure 6. Boolean maps. This shows an example of how two different objects would be represented on Boolean maps. Both red objects can be represented together on a Boolean map that is representing the location of red items (the top example). However, the red and green features of a red-and-green object (bottom) must be accessed serially and are therefore represented on separate maps.

performance will be better if the two features are presented sequentially. On the other hand, if the two colors can be accessed at the same time (in parallel), then performance should be equal in the simultaneous and sequential conditions. Importantly, the features are presented very briefly (~20-60ms) and then masked to disrupt additional processing. This suggests that, if the two features must be accessed serially, then when presentation is simultaneous, very often only a single mask can be created, leading to lower performance in the simultaneous condition. Huang and Pashler (2007) found that participants were more accurate at identifying the test color when the study colors were presented sequentially, suggesting that the two colors must be accessed serially. These results have been replicated with orientation (Liu & Becker, in press; in this study, this process was referred to as *consolidation into memory*, rather than *access*), although replication of these results for colors is somewhat ambiguous (Mance, Becker, & Lui, 2012).

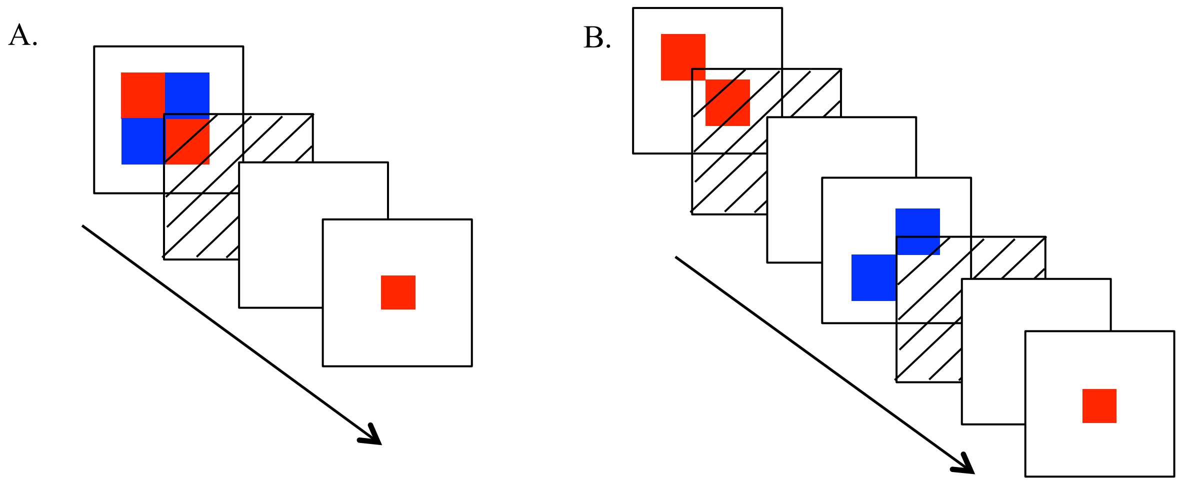


Figure 7. Simultaneous-sequential paradigm. This figure shows an example of the simultaneous-sequential paradigm from Huang and Pashler (2007). In A, two colors are presented sequentially, while in B, the two colors are presented simultaneously. If performance is equal in these two conditions, this would indicate that the two colors are accessed in parallel. If performance is higher in the sequential condition, this would indicate that the two colors must be accessed serially.

This is relevant to the question of the unit of representation in VWM because it emphasizes that two different colors must be represented on different maps. If a Boolean map serves as the unit of representation in VWM, this would explain why two colors do not show an object benefit: even when they are combined into a single object, they still must be accessed serially, and therefore on separate maps. Therefore, even though the number of objects is reduced by combining two colors into a single object, the number of Boolean maps stays the same. Imagine again the red-and-white Mini Cooper. This car can clearly be recognized as an object - there is no confusion to the viewer about whether the car is really two objects, one red car body and one white roof. However, it is clear that the car is composed of two distinct colors:

red and white. Therefore, the red and white colors still must be accessed serially, even though the are next to each other as part of an object.

In addition, the Boolean map hypothesis can also offer an explanation about why two combined shapes do show an object benefit in VWM (Kim & Kim, 2011). When two shapes are connected to form a single *object*, this object creates a new shape that is different from each of the individual shapes. Therefore, both shape features can be accessed in parallel. However, when two shapes are separated (to create two objects) each shape feature must be accessed serially. For example, imagine a car that is painted a solid color. This car is made up of several different parts (e.g., bumper, door, etc.). If the car were to be disassembled into these various parts, each part would have its own shape and would be recognizable on its own. If all of these parts were lying on the ground, each of these individual shapes would be accessed serially. However, when these parts are combined into a car, the whole car is viewed as a single object, not as several pieces. The new overall shape of the car is accessed as a whole, and therefore all of the 'shapes' that make up the car can now be accessed in parallel. To support this explanation, however, it still must be determined: 1) whether two different shape values are accessed serially and 2) whether, when these shapes are combined into a unified whole, both shape features can be accessed in parallel (Experiment 2).

At this point, it has not been determined whether two different shape features would necessarily be represented on two different maps. In a footnote, Huang and Pashler (2007) suggested that shape information is automatically included in a Boolean map. However, in Huang (2010), it was suggested that access to two different shapes would be more difficult than access to a single shape and that a Boolean map is only a collection of locations, with a single feature 'tag' per dimension that can be applied to the entire map. Further more, while it has been demonstrated that multiple colors must be accessed serially (Huang & Pashler, 2007, but see Mance et al, 2012) as well as multiple orientations (Lui & Becker, in press), it has yet to be directly tested whether two different shape values must be accessed serially. Given the more recent suggestion that Boolean maps contain no identity information (Huang, 2010) and the results of Kim and Kim (2011) that two shapes can be combined to create an object benefit in VWM, it was predicted that two different shape values would also be represented on separate Boolean maps. This prediction was directly tested in Experiment 2.

The Boolean map so far has offered an explanation about the conditions under which two features from the same dimension will show an object benefit in VWM. The Boolean map hypothesis also predicts that two features from different dimensions will show an object benefit in VWM. This is because, according to the Boolean map hypothesis, two features from different dimensions can be accessed in parallel and therefore represented on the same map (see Figure 8). This prediction is tested directly in Experiment 2.

This study will investigate whether the Boolean map serves as a unit of representation in VWM. The Boolean map hypothesis suggests that VWM capacity is limited by the number of Boolean maps, not the number of objects. In many situations, these two numbers may be identical (as with colored shapes). For example, when two features from different dimensions are combined into a single object, this results in both fewer objects and fewer Boolean maps. Therefore, both the Boolean map and the object hypotheses would predict an object benefit in this situation. However, there are circumstances in which the number of objects and the number of Boolean maps differ, such as with bi-colored squares. With bi-colored squares, there are fewer objects compared to when the two colors are split apart. According to the Boolean map hypothesis, however, two unique features are always represented on separate Boolean maps. In this case, the Boolean map hypothesis would predict that there should be no object benefit.

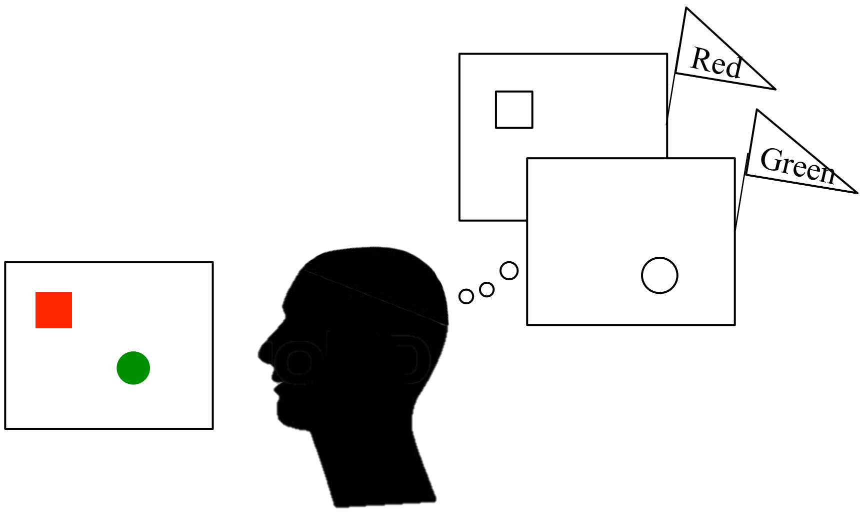


Figure 8. Two dimension Boolean maps. This figure shows an example of how both features of an object are represented on the same Boolean map, provided both features are from different dimensions.

The Boolean map has two distinct advantages over both the traditional object and feature hypotheses. First, it predicts that *both* objects and features affect how much information is represented in VWM. Second, it predicts that combining features from the same dimension would affect memory differently than combining features from different dimensions. These patterns are both observed in the VWM literature. Therefore, this study will examine whether the Boolean map is the unit of representation in VWM. According to the Boolean map hypothesis, if two features can be accessed in parallel when they are combined into a single object, those two features should also show an object benefit in VWM.

Finally, according to Boolean map theory (Huang, 2010), objects likely operate as the unit of selection, while Boolean maps operate as the unit of access. Therefore, it is possible to select two features together that are perceived as single object, but still access the two features serially. That is, object-based attention may operate over a stimulus but the two features may still be accessed serially. Therefore, an alternative way of thinking about the current question of interest is whether the unit of representation in VWM is more closely aligned with the unit of selection or the unit of access. Therefore, the Boolean map hypothesis predicts that it is possible for certain stimuli to show an object-based spread of attention (indicating that the stimulus is perceived as an object), even if the features of the object must be accessed serially.

1.6 The Current Study: Objects or Boolean Maps?

The purpose of this study was to compare the object and Boolean map hypotheses to determine which hypothesis better illustrates the unit of representation in VWM. Three experiments were conducted to examine this question. First, the object hypothesis was tested by examining the stimuli that showed object-based attention (Experiment 1) and determining whether those same stimuli demonstrated an object benefit in VWM (Experiment 3). Second, the Boolean map hypothesis was tested by examining the features that can be accessed in parallel (Experiment 2), and comparing that to the features that, when combined, showed an object benefit in VWM (Experiment 3).

Experiment 1. According to the object hypothesis, the object serves as the unit of representation in VWM. An object benefit does not occur for bi-colored squares because the heterogeneous surface features (indicating two objects) prevents these stimuli from being attended as objects. Only objects that show automatic, object-based spread of attention should show an object benefit in VWM. The object hypothesis was tested first in Experiment 1 by examining whether object-based attention occurs for multiple types of stimuli (see Figure 9). Four of these stimuli, the colored shapes, bi-shape stimuli, bi-shape gap stimuli, and bi-color stimuli, were used in all three experiments.

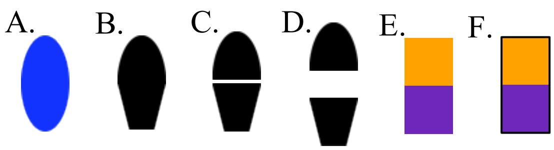


Figure 9. Stimuli for this study. Example A shows a colored shape, B a bi-shape, C a bi-shape gap, D., separated, E., bi-color, and F. a bi-color border. The objects shown in A, B, C, and E were also used in Experiments 2 and 3.

Given that colored shapes and bi-shape stimuli have demonstrated an object benefit in VWM in previous literature (Kim & Kim, 2011; Luria & Vogel, 2011), the object hypothesis predicts that an automatic spread of attention should occur for these stimuli. The bi-shape gap stimuli were identical to the bi-shape stimuli, except that they had a small gap between the top and bottom shapes. This gap prevented the two shapes from sharing a homogenous surface feature in order to prevent them from being attended as a single object (Palmer & Rock, 1994); this gap also allowed the participants to easily detect two distinct shapes. It was predicted that the automatic spread of attention would not occur for the bi-shape gap stimuli because the gap serves to create a heterogeneous surface feature. However, because the top and bottom shapes in the bi-shape gap condition are closer to each other than to the other object on the screen, it is still possible to perceptually 'group' these features based on their proximity to each other (Palmer & Rock, 1994). Therefore, a *separated* condition was created in which the space between the two shapes of a bi-shape stimulus was much larger than the space in the bi-shape gap condition. Specifically, the size of this space was created so that the distance between the two shapes within an object was the exact same distance as the distance between two different objects. This purpose of this condition was to make it clear that the two shapes were not part of the same object. The separated condition served as a control because it should not show *any* object-based spread of attention. This was used to confirm that any object-based spread of attention in the other stimuli were caused by object-based attention, and not any other factors (e.g., shifting attention from left to right).

The test of object-based attention was also conducted on bi-color stimuli. Because the object benefit does not occur in VWM for bi-colored stimuli (Xu, 2002), the object hypothesis predicts that an automatic object-based spread of attention should not occur for bi-colored stimuli. Finally, a bi-color border condition was included in Experiment 1. These stimuli were identical to the bi-color stimuli, with the exception that a black border surrounded both colors. This border acted as a perceptual cue that the two colors belonged to the same object. Matsukara and Vecera (2006) found that there was object-based attention for objects with heterogenous surface when the objects were enclosed by a black border. Therefore, the bi-color border stimuli were included to determine if there was a difference in the spread of object-based attention across bi-color stimuli with and without the border. The purpose of this condition was to determine whether an object benefit in VWM *could* arise for two colors if the bi-colored stimuli could be attended as a single object (i.e., the border stimuli). However, there was no difference in the spread of attention between the bi-color and bi-color border stimuli, so in Experiments 2 and 3, only the bi-color stimuli were used.

Experiment 2. According to the Boolean map hypothesis, the object benefit does not occur for two features from the same dimension (e.g., bi-colored squares) because each feature must be attended serially and therefore must be represented on separate maps. Therefore, only features of an object that can be attended in parallel will show an object benefit in VWM. The Boolean map hypothesis was tested with the simultaneous-sequential paradigm of Huang and Pashler (2007); if two features can be attended in parallel, performance should be the same when the features are presented sequentially and when they are presented simultaneously. If two features must be accessed serially, performance should be higher when the features are presented sequentially. Experiment 2 tested two separate hypotheses. Experiment 2a tested whether two features from the same object can be accessed in parallel; Experiment 2b tested whether two identical features from different objects can be tested in parallel.

First, experiment 2a tested whether two features of the same stimulus can be accessed in parallel using four of the same stimulus types in Experiment 1: the colored shapes, bi-shape, bi-shape gap, and bi-colored stimuli. Each of these stimulus types contained two features (the colored shapes are composed of a color and a shape, the bi-shape and bi-shape gap contain two shape features each, and the bi-color contain two colors). The two features of a single stimulus were presented either simultaneously or sequentially.

According to the Boolean map hypothesis, when two features that are combined into a single object are accessed in parallel, they can be represented together on the same map. Therefore, an object benefit should occur in VWM. Therefore, it was predicted that both features would be accessed in parallel (i.e., no sequential presentation benefit) for the stimuli that show an object benefit in VWM. This suggests that both features of the colored shapes (i.e., the color and the shape) and bi-shape stimuli (i.e., both shapes) should be accessed in parallel. In contrast, the two features of the bi-shape gap stimuli should be accessed serially because the gap separates the two shapes features, preventing them from being accessed together as a single shape. In addition, each feature of the bi-color objects should be accessed serially because these stimuli typically do not show an object benefit in VWM.

Experiment 2b tested the prediction that two identical feature values can be accessed in parallel. Huang and Pashler (2007) found that the locations of two identical objects could be accessed in parallel. Participants viewed two identical squares in separate locations (either sequentially or simultaneously). At test, participants were probed about the potential location of one of the items. In this experiment, performance was equal in the simultaneous and sequential conditions, suggesting that it is possible to identify both locations of two items in parallel. However, it has not yet been determined whether two identical shape values can be accessed in parallel.

In Experiment 2b, the claim that two identical feature values can be attended in parallel (and therefore represented on the same Boolean map) was tested for shapes and colors. The Boolean map hypothesis predicts that there should be no sequential advantage for two identical features (e.g., two squares), because two identical features can be accessed in parallel. However, there should be a sequential advantage for two features that are different (e.g., a red square and a blue square). This was tested in Experiment 2b by including two trial types: trials where the study features were identical to each other and trials where the two study features were different from each other. According to the Boolean map hypothesis, there should be a sequential advantage when the two study colors are different from each other, but not when they are the same.

The idea that two identical feature values can be accessed in parallel is an important component of the Boolean map hypothesis. This component was directly tested in Experiment 2b because the effect of repeating feature values on memory was tested in Experiment 3. Specifically, the Boolean map hypothesis proposes that repeated feature values (e.g., two squares) should be stored on the same Boolean map. If feature values are repeated, then shared features can be represented together on the same Boolean map. Therefore, in Experiment 3, if feature values are repeated, the object benefit should be reduced (or eliminated).

Experiment 3. Experiment 3 tested the object benefit in VWM for the same colored shape, bi-shape, bi-shape gap, and bi-color stimuli that were used in Experiments 1 and 2a. Experiment 3 utilized a change detection task in which two features of a stimulus were either presented separately, as two objects (disjunction condition) or together, as part of the same object (conjunction condition). Higher performance in the conjunction condition than the disjunction condition indicates an object benefit. According to the object hypothesis, any objects that show an automatic, object-based spread of attention in Experiment 1 should also show an object benefit in Experiment 3. According to the Boolean map hypothesis, if two features of a particular stimulus type can be accessed in parallel in Experiment 2, those stimuli should show an object benefit in VWM in Experiment 3.

In addition, the uniqueness of the feature values in a display was manipulated. That is, in some displays, all of the feature values within a display were different from one another (unique condition). In other displays, some of the feature values were repeated (e.g., two circles; repeated condition). According to the Boolean map hypothesis, two identical feature values can be represented on the same Boolean map. For example, a display that contains two unique shapes will result in the creation in two Boolean maps. In contrast, a display that contains two identical shapes will result in the creation of one Boolean map. In addition, a display that contains a single shape will also result in the creation of one Boolean map. Therefore, repeating feature values serves the same purpose as combining two features into a single object: reducing the total number of representations (Boolean maps) stored in VWM. Therefore, according to the Boolean map hypothesis, there should be no additional advantage created by combining two features into an object (i.e., no object benefit) if feature values are repeated. Therefore, the object benefit should occur only when feature values are unique.

Predictions. The object hypothesis predicts the following pattern of results across Experiments 1 and 3. Any stimuli that show object-based attention in Experiment 1 should also show an object benefit in Experiment 3. Based on previous research, it was expected that colored shapes and bi-shape objects would show object-based attention, but bi-color objects and bi-shape gap objects would not. Therefore, colored shapes and bi-shape objects should be the only stimuli to show an object benefit in VWM in Experiment 3. Furthermore, the object benefit should not be affected by the repetition of feature values in the memory display (Experiment 3). Therefore, any stimuli that show an object benefit when feature values are repeated should also show an object benefit when feature values are unique.

The Boolean map hypothesis predicts the following pattern of results across Experiments 2 and 3. First, an object benefit in VWM should occur (Experiment 3) only when both features of a stimulus can be accessed in parallel (Experiment 2a). Based on previous research, it was predicted that both the color and shape of a colored shape would be accessed in parallel and that both shapes of a bi-shape object would be accessed in parallel. However the two shapes of a bi-shape gap object would be accessed serially and the two colors of a bi-color object would be accessed serially. Second, it was predicted that, in Experiment 2b, when the two study features were different, both features would be accessed serially. However, when the two study features were identical, both features would be accessed in parallel. This would indicate that identical feature values are accessed in parallel, even when they are different objects. Therefore, the object benefit in VWM (Experiment 3) should be decreased or eliminated when feature values were repeated.

CHAPTER 2. EXPERIMENT 1: OBJECT-BASED ATTENTION

Experiment 1 tested object based attention for colored shapes, bi-shape, bi-shape gap, separated, bi-color, and bi-color border stimuli. This experiment used a test of object-based attention modeled after Egly et al. (1994). Participants viewed two objects presented side by side. One end of an object was briefly cued, followed by a target. The goal of the participant is to respond as quickly as possible. Object-based attention is indicated by faster target detection when the target appears in the cued object compared to when the target appears in the uncued object. Based on previous research that bi-colored objects do not show an object benefit in VWM, object based attention was expected for the colored shapes and the bi-shape objects only. In addition, it was expected that although bi-color objects should not produce object-based attention, the bi-color border objects might because the border may act as a perceptual cue to indicate that the two colors are part of the same object (Hecht & Vecera, 2007).

2.1 Method

Design. This experiment utilized a 4 (trial type) x 6 (stimulus type) mixed design. Trial type (valid, invalid within object, invalid between object, and target absent) was manipulated within subjects, while stimulus type (colored shape, bi-shape, bi-shape gap, separated, bi-color, bi-color border) was manipulated between subjects.

Participants. One hundred forty-four undergraduate psychology students participated in this experiment for course credit (91 female, average age = 20.02). All students reported normal color vision and 116 students reported normal or corrected-to-normal vision. Nineteen students participated in the colored shape condition, 26 in the bi-shape condition, 25 in the bi-shape gap condition, 21 in the separated condition, 27 in the bi-color condition, and 26 in the bi-color border condition.

Stimuli. Eight different colors (blue, brown, cyan, green, purple, brown, pink, red) and eight different shapes were used to create all stimulus types (see Figure 10). Each of the eight shapes were symmetrical about the y axis and were the same width at the base. Therefore, two different shapes (one upright, one inverted) could be combined to create a new, unified object composed of two distinct shape features. Using these eight shapes and eight colors, six different stimulus types were created, four of which were used in all three experiments (see Figure 9, page 27). Each shape and colored square subtended 1.4 degrees of visual angle from a viewing distance of approximately 40cm (computer screens were placed 40cm from the edge of the table, but viewing distance of the participants was not controlled).

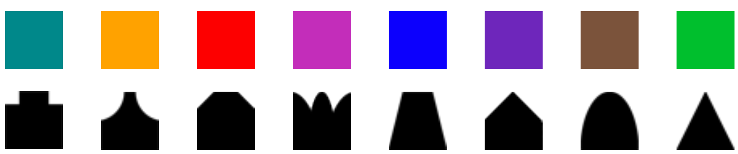


Figure 10. All colors and shapes. This shows all eight colors and shapes that were used to create all of the stimulus types used in the current experiment.

1. *Colored shapes* were composed of two identical shapes (one upright and one inverted) that were combined to form one large shape that was symmetrical about the x and y-axes. This entire shape was then filled with one of the eight possible colors.
2. *Bi-shape simuli* were composed of two different black shapes (one upright, one inverted) combined to form unified stimuli.
3. *Bi-shape gap stimuli* were identical to the unified bi-shape stimuli except that they were separated by a small space.
4. *Separated* stimuli were similar to the bi-shape gap stimuli, except that the space between the two shapes was very large (approximately 5 degrees visual angle). The size of the gap was equal to the distance between two objects. Therefore,

when two *separated* stimuli were presented side by side, the configuration resembled four separate shapes, each equidistant apart (see Figure 11).

5. *Bi-color stimuli* were composed of two colored squares presented one on top of the other.
6. *Bi-color border stimuli* were identical to the bi-color stimuli except that a black border surrounded the entire object.

Each trial array contained two objects presented side by side, separated by a distance of .5 degrees of visual angle, with a fixation cross between each object. Arrays never contained two identical color or shape features. Cues were gray in color and conformed to the top half of each shape. Targets were small white dots (.3 degrees of visual angle).

Procedure. Participants viewed two stimuli side by side for 1000ms (see Figure 11). The two stimuli were always different from each other (no features were presented twice within an array), but were from the same stimulus category (e.g., two colored shapes). Then, a cue appeared on one end of one of the objects for 100ms. This cue appeared as a gray frame around one end of one of the objects. After a 200ms ISI, a target (a white dot) appeared in one of the objects for two seconds, or until the participants responded. Participants were instructed to respond to the target as quickly as possible by pressing the spacebar on a keyboard.

The target would appear in one of three locations (see Figure 11). In the valid trials, the target appeared in the cued end of an object. In the invalid within-object trials, the target appeared in the uncued end of the cued object. In the invalid between-object trials, the target appeared in the uncued object. On the invalid between-object trials, the target always appeared on the end of the uncued object that was adjacent to the cued location (that is, the target never appeared diagonally from the cue).

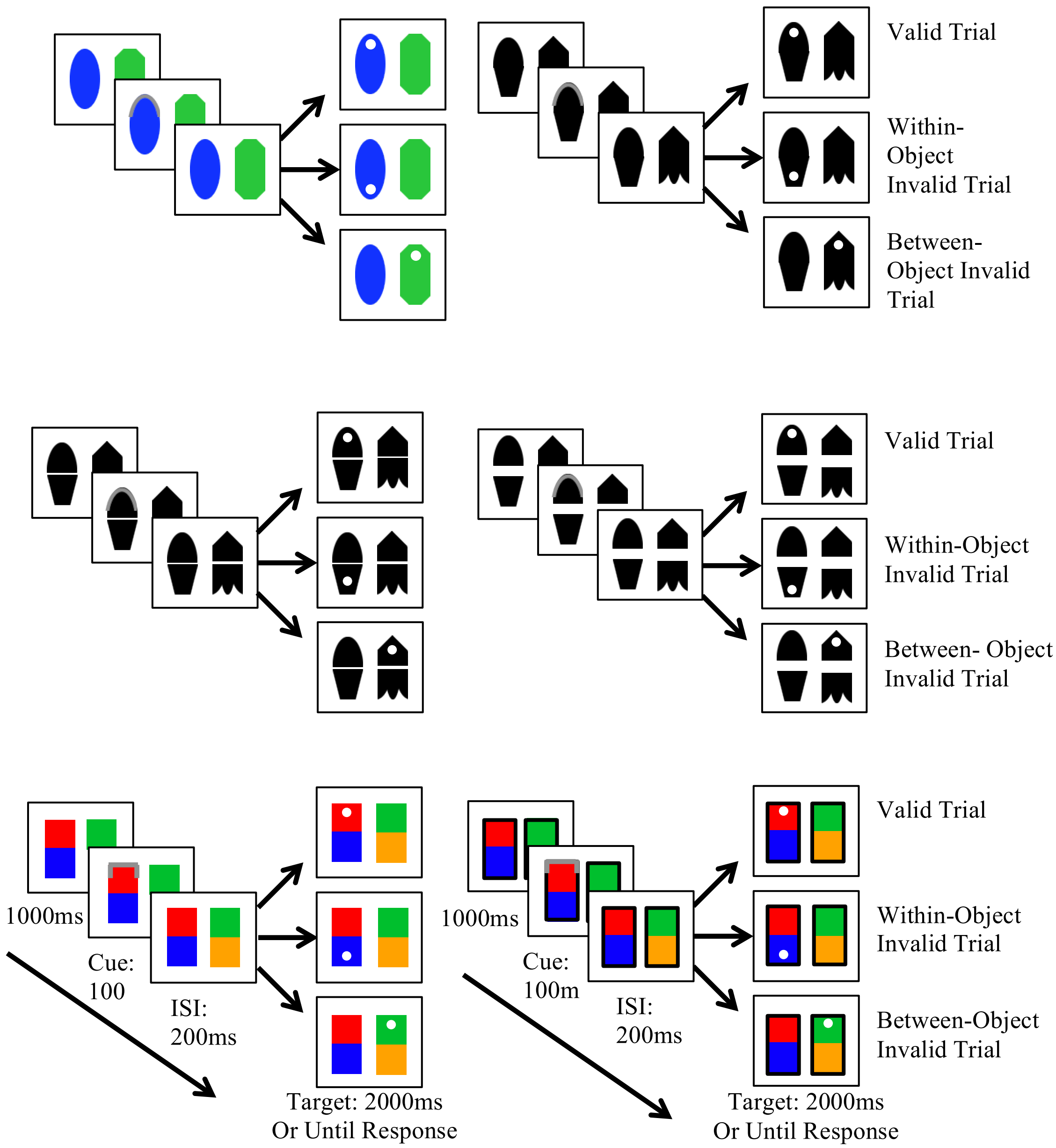


Figure 11. Procedure for Experiment 1. Participants viewed two objects side by side. One end of an object was cued with a gray frame for 100ms. The frame disappeared and a target appeared in one of three locations: the cued location (valid trial), the opposite end of the cued object (within object invalid trial) or the uncued object (between-object invalid trial).

On some trials, there was no target and participants were instructed to withhold their responses. These no-target trials served as 'catch' trials to ensure that participants only responded to the target. Without these no-target trials, the cue could serve as a temporal warning cue, indicating that the onset of the target is soon. This could encourage participants to engage in a strategy where they respond to the cue, rather than responding to the target, resulting in predictable response times that would fail to capture any object-based shifts of attention. The no-trial cues were in place to make sure that participants only responded after the target actually appeared. If participants responded on a no-target trial, or if participants responded too quickly (less than 150 after the appearance of the target), they heard a warning tone. Responses that were too fast were excluded from analysis.

Participants first completed a practice block of 76 trials (48 valid trials, 8 invalid within trials, 8 invalid between trials, and 12 no-target trials). This was followed by the experimental phase of 240 valid trials 40 invalid within object trials, and 40 invalid between object trials and 64 no-target trials, divided into four blocks of 96 trials each (the order of the trials was randomly distributed across the entire experiment; therefore, the number of trials of each type was not identical in every block). Seventy-five percent of all target-present trials were valid trials and 25% were invalid trials. This high proportion of valid trials meant that the cue was predictive of the target location. This was to ensure that it would be advantageous for the participants to orient attention to the cued location. In addition, participants were instructed that the targets would appear frequently in the cued location; however, participants were also instructed that the target could appear in any location and that the best strategy would be to keep their eyes in the center of the display.

2.2 Results

Overall performance was very good: participants incorrectly gave a response on only 2.9% of all target-absent trials and responded too quickly on 1.8% of all target-present trials. Target-present trials on which the participants responded too quickly (in less than 150ms from the onset of the target) were excluded from analysis. For each stimulus type, mean response times on the invalid trials were subtracted from response times (RT) on the valid trials as a measure of the cost to respond when the target appeared in a non-cued location. Paired sample t-tests were conducted for each stimulus type to compare the *between object cost* (between object invalid RT – valid RT) to the *within object cost* (within object invalid RT – valid RT); see Figure 12. The results indicated that object-based attention was present for all stimulus types except the separated stimuli.

Colored shapes. Paired sample t-tests revealed that the between object cost ($M = 66.58$, $SD = 35.99$) for the colored shapes was significantly greater than the within object cost ($M = 9.53$, $SD = 23.86$), $t(18) = 7.88$, $p < .001$, $d = 1.46$.

Bi-shape. For the bi-shape stimuli, the between object cost ($M = 31.01$, $SD = 23.06$) was significantly greater than the within object cost ($M = 4.44$, $SD = 15.84$), $t(25) = 4.29$, $p < .001$, $d = 1.49$.

Bi-shape gap. For the bi-shape gap stimuli, the between object cost ($M = 33.51$, $SD = 23.40$) was significantly greater than the within object cost ($M = 20.29$, $SD = 21.13$), $t(24) = 3.36$, $p = .003$, $d = .67$.

Separated. Although in the separated condition, all four features were equidistant, trials were coded as within an object if the target appeared in the shape that was above or below the cued object, and between object if the target appeared in the shape to the left or the right of the cued object. This way, coding of within or between was consistent with other five stimulus types.

Paired sample t-tests revealed that the between object cost ($M = 26.08$, $SD = 33.64$) was not significantly different than the within object cost ($M =23.65$, $SD = 29.53$), $t(20) = .29$, $p = .772$, $d = .07$.

Bi-color. For the bi-color stimuli, the between object cost (M = 29.47, SD = 19.22) was significantly greater than the within object cost (M = 11.51, SD = 15.48), $t(26) = 4.51$, $p < .001$, d = .90.

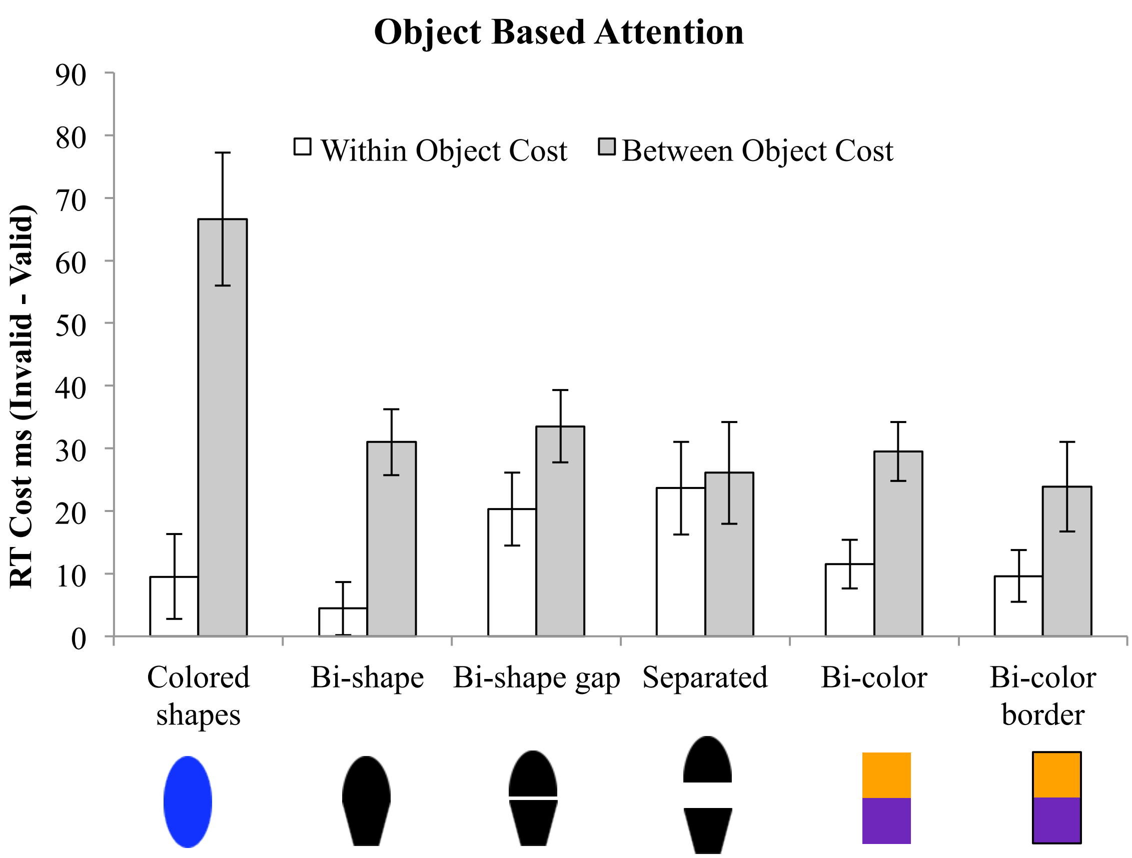


Figure 12. Results of Experiment 1. Evidence for object-based attention is found when the between object cost is greater than the within object cost. All stimulus types, with the exception of the separated stimuli, demonstrated an object-based spread of attention. Error bars represent standard error.

Bi-color border. The between object cost for the bi-color border stimuli (M = 30.79, SD = 21.34) was significantly greater than the within object cost (M = 11.18, SD = 16.69), $t(20)$ = 4.09, p = .001, d = .63.

2.3 Discussion

The results of this study showed that an automatic object-based spread of attention occurred for all stimulus types (with the exception of the separated stimuli). Therefore, all stimuli, including the bi-color stimuli, were attended as objects. This suggests that the lack of VWM object benefit for bi-colored stimuli in previous research was likely not because participants did not attend to these stimuli as objects.

Interestingly, the bi-shape gap stimuli showed an automatic spread of attention. This suggests that grouping principles, such as proximity, are sufficient for the viewer to override the blank space and still group together the slightly separated shapes as an 'object' for the spread of attention. Importantly, the separated stimuli did not show any object-based attention. This suggests that the presence of object-based attention for the bi-color and the bi-shape gap stimuli *was* caused by an object-based spread of attention and not some other factor (e.g., switching attention from the left to the right).

Because the colored shapes, the bi-shape, bi-shape gap, and bi-color objects all showed an automatic spread of object-based attention, the object hypothesis predicts that in Experiment 3, all of these object types will show an object benefit in VWM. Also, because there was evidence for object-based attention for both the bi-color and bi-color border stimuli, only the bi-color stimuli were used in Experiments 2 and 3.

CHAPTER 3. EXPERIMENT 2: BOOLEAN MAPS

Experiment 2 investigated the Boolean map hypothesis by testing whether two features are attended serially or in parallel. Two features were presented either sequentially or simultaneously. Higher recognition accuracy when the features are presented sequentially than when they are presented simultaneously suggests that the two features must be accessed serially. Equal performance in sequential or simultaneous presentation suggests that the two features can be accessed in parallel. Experiment 2a tested parallel and sequential access for two features of a single stimulus when the two study features were different from each other, as in Huang and Pashler (2007). Experiment 2b tested the hypothesis that two identical features can be accessed in parallel by comparing the sequential advantage when the two study features were the same as each other compared to when the two study features were different from each other.

3.1 Experiment 2a

Experiment 2a tested serial and parallel access for colored shapes, bi-shape, bi-shape gap, and bi-color stimuli. In Huang and Pashler (2007), participants viewed two study features and a single test feature. This procedure was followed in Experiment 2a. However, for the bi-shape stimuli, when both shape features are presented simultaneously, they are integrated in a way that may make it difficult to identify the individual shape features. Therefore, it may be difficult to identify a single shape at test. This may result in a sequential advantage not because both shape features are accessed serially, but because it is difficult for the participant to recognize each shape feature individually. This should not be a problem for the bi-shape gap stimuli, because the gap clearly marks the distinction between the two shapes. Therefore, for the bi-shape and bi-shape gap stimuli, an additional test was completed in which participants saw both features at test and had to identify whether both features were the same, or whether one was different (the “full-test” conditions). This may improve performance in the simultaneous condition for the bi-shape stimuli, but it should have no effect on the bi-shape gap stimuli.

Method.

Design. This experiment utilized a 2 (presentation type) x 6 (stimulus type) mixed design. Presentation type (simultaneous, sequential) was manipulated within subjects, while stimulus type (colored shape, bi-shape, bi-shape full test, bi-shape gap, bi-shape gap full test, and bi-color) was manipulated between subjects.

Participants. Seventy-five undergraduate students (55 female, average age = 19.76) participated in this experiment for credit in their undergraduate psychology courses. The stimulus types were manipulated between subjects. Eleven students participated in the bi-shape condition, 12 in the bi-shape full-test, 12 in the bi-shape gap, 15 in the bi-shape gap full-test, 12 in the colored shapes, and 12 in the bi-color. Seventy participants reported normal or corrected-to-normal vision, and all but two participants reported normal color vision. Two of the participants did not give a response about color vision, but their average accuracy was within 1 SD of the mean and excluding these participants did not alter the results. Therefore, all participants were included in the analyses.

Stimuli. Participants saw the same four stimulus types in Experiment 1 (colored shapes, bi-shapes, bi-shape gap objects, and bi-color objects). In the sequential condition, participants saw two study screens, each with only one feature. In the simultaneous condition, participants saw only one study screen that contained both study features. In the sequential condition, study features were presented either to the top or bottom of fixation, in the same locations they would have been if they were presented simultaneously (see Figure 13). In addition, masks were created that subtended 8 (height) x 4 (width) degrees of visual angle. Test features were always presented in the very center of the screen. For the colored shapes, in the simultaneous presentation, the full colored shape was presented as the study stimulus. In the sequential presentation, the shape (black) was presented separately from the color (square) was presented. A single test feature (either a black shape or a colored square) was presented in the center of the screen.

Procedure. The general procedure was the following: participants viewed two study features, followed by a test feature, and determined whether the test feature matched one of the study features or whether it was new (by pressing one of two keys on a keyboard: 'z' or '/'). For each stimulus type, participants completed trials of two different presentation types that were randomly intermixed: simultaneous presentation and sequential presentation.

Simultaneous presentation**.** In the simultaneous presentation trials, both features were presented on the screen at once (20ms for bi-color stimuli, 50ms for all other stimuli). This was followed by a 200ms mask, then a 500ms blank screen ISI, then a single test feature. This test feature either matched one of the study features, or it was new. Participants indicated whether the test feature was old or new. In the colored shape condition, the test feature was either a colored square or a black shape. If the test feature was a color, participants indicated whether the color matched the color of the colored shape; if the test feature was a shape, participants indicated whether the shape matched the study shape. Both study features were tested equally often (either the top or bottom feature for the bi-shape, bi-shape gap, or bi-color and either the color or shape for the colored shapes)

Sequential presentation. A single feature was presented (20ms in the bi-color condition, 50ms in all other conditions), followed by a 200ms mask, a 500ms ISI, the second feature, followed by a second mask and ISI, then the test feature. Both the first and second study features

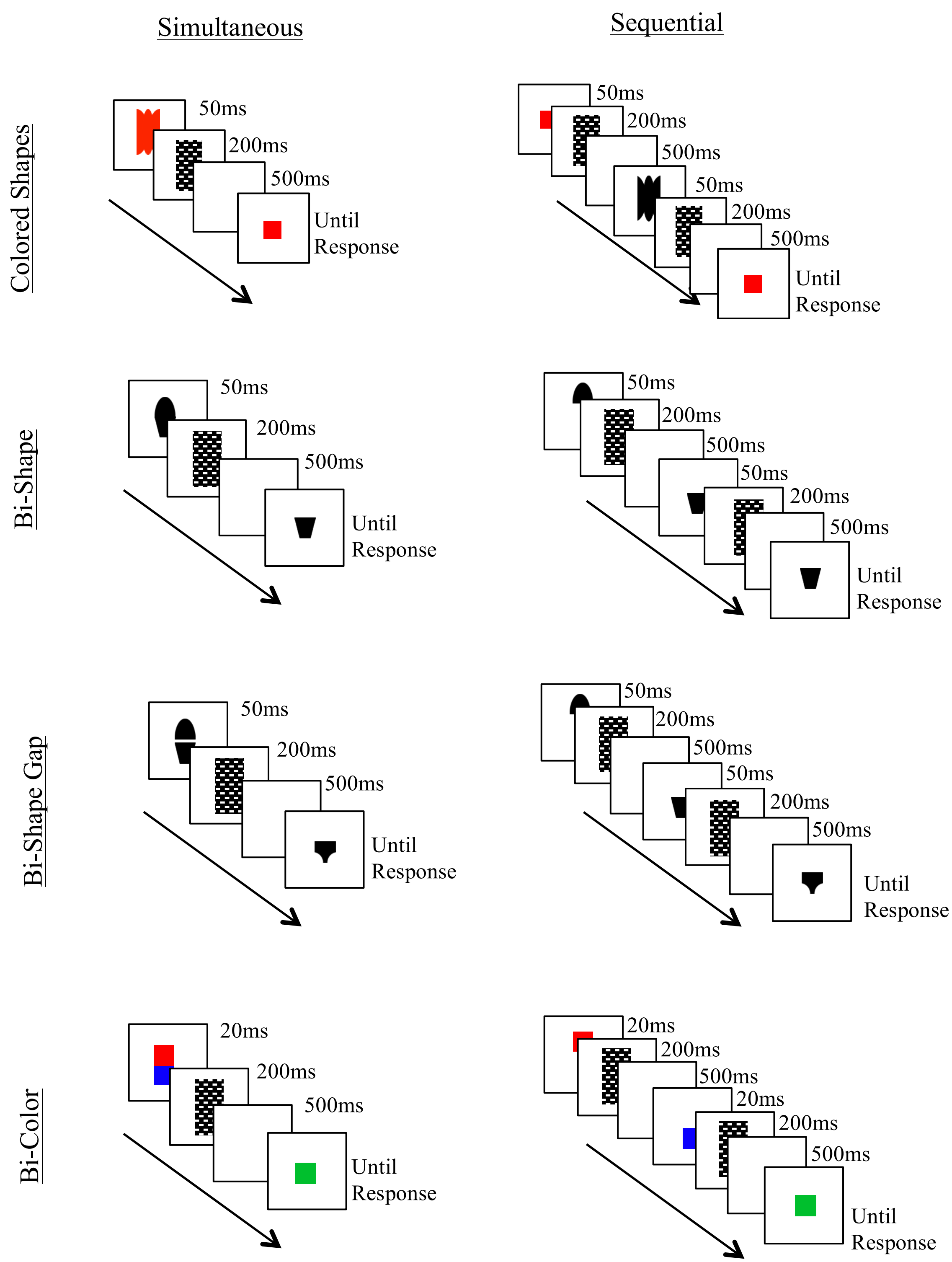


Figure 13. Procedure for Experiment 2a. Participants viewed two study features indicated whether the test feature matches either study feature. The colored shape and bi-shape examples demonstrate a trial in which the test is old. The bi-shape gap and bi-color examples demonstrate trials in which the test feature is new.

were tested equally often. In the colored shape condition, participants saw a colored square and a black shape as their study features. They were instructed that they only had to detect the color of the square and the shape of the black shape. Colors and shapes were both the first feature presented an equal number of times. Participants saw either a color or a shape at test; participants were tested on the color and shape of the study features an equal number of times.

Full-test (bi-shape and bi-shape gap only). For the bi-shape stimuli, it may have been difficult for participants to identify only a single feature at test (in the simultaneous presentation condition) because when both features were combined, it may have been difficult to discriminate each feature separately (as the two features were combined specifically to resemble a single unified object). That is, it was predicted the factor that should two shapes to be accessed in parallel is that, when combined, they form a new shape with a uniform surface feature. This connection may make it difficult for the participant to perceive each unique shape feature, which could lead to a sequential advantage. Therefore, higher performance in the sequential condition for bi-shape stimuli may reflect an inability to perceive two distinct features in the simultaneous condition, rather than an inability to access both features in parallel. Therefore, for both the bi-shape and bi-shape gap stimuli, additional tests were run in which two features were shown at test instead of only one feature (the full test stimuli). Participants had to identify if *both* of the tests shapes matched the study shapes, or if either one of the features were new (see Figure 14).

All conditions. Before the experiment began, participants completed an instruction phase in which they viewed a figure that showed the procedure of a hypothetical trial. Participants indicated what the correct answer was for the hypothetical trial. Participants were given feedback to their response. If their response was correct, the figure disappeared and they saw the word “correct” in green. If their response was incorrect, they saw the same figure of the hypothetical trial, but with the correct answer given and an explanation about what the correct answer was and why. Participants saw a hypothetical trial for all potential trial types (e.g., simultaneous-old, simultaneous-new, sequential-old, sequential-new). Participants only left the instruction phase once they gave a correct response to all hypothetical trials.

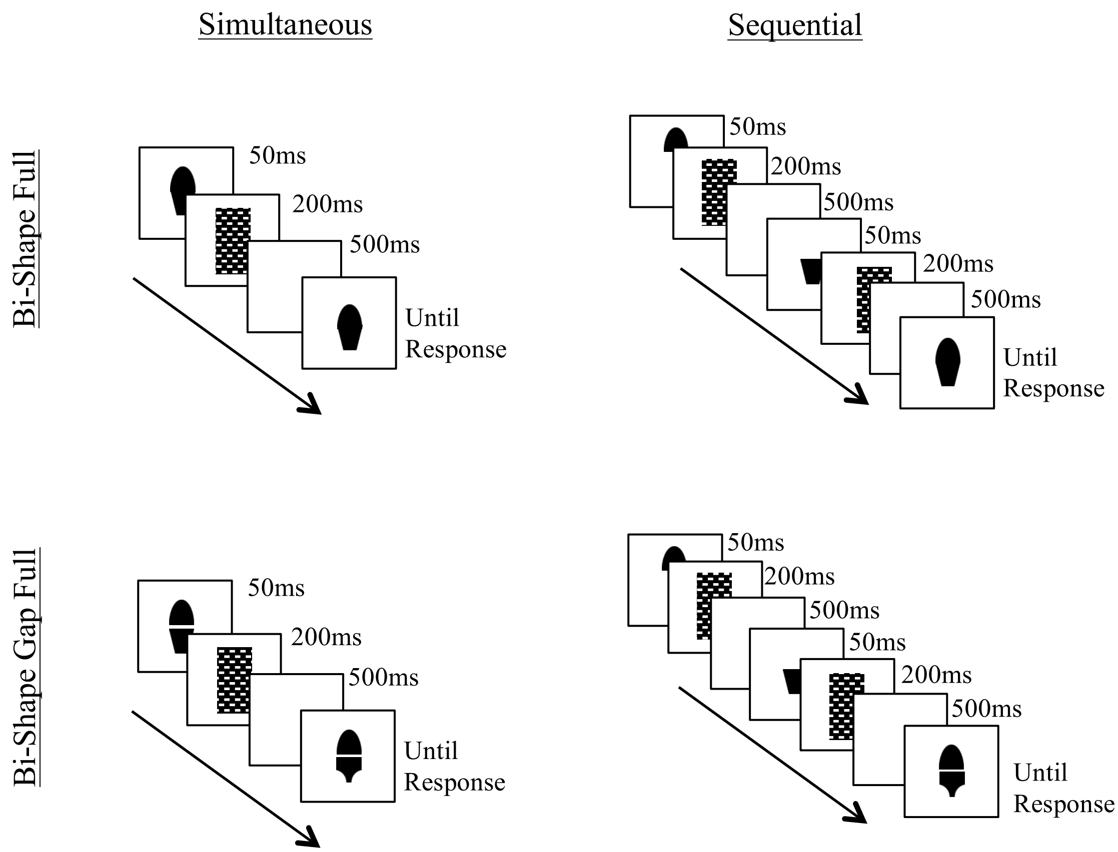


Figure 14. Procedure for full test. This shows the full test conditions for the bi-shape and bi-shape gap stimuli. The bi-shape stimuli (the two top examples) show an example where the both features at test matched the study features, while the bi-shape gap stimuli (the bottom two examples) show an example where one of test features was new (the bottom shape).

Participants completed a block of 64 practice trials (half simultaneous, half sequential), followed by four blocks of test trials. Across all four test trials, participants completed at total of 256 simultaneous presentation trials and 256 sequential presentation trials, randomly intermixed. Half the trials were new trials and half were feature old trials. In the colored shape condition, half the trials had a shape as the test feature, and half of the trials had a color as the test feature.

Results. For each stimulus type, paired sample t-tests compared proportion correct on the simultaneous and sequential conditions (see Figure 15). A sequential advantage (higher performance in the sequential presentation than the simultaneous presentation) indicates that the two features must be accessed serially while equal performance on the sequential and simultaneous trials indicates that the two features can be accessed in parallel. A sequential advantage was found for the bi-shape, bi-shape gap and bi-shape gap full test stimuli. There was no sequential advantage for the colored shapes, bi-shape full test, or bi-color stimuli.

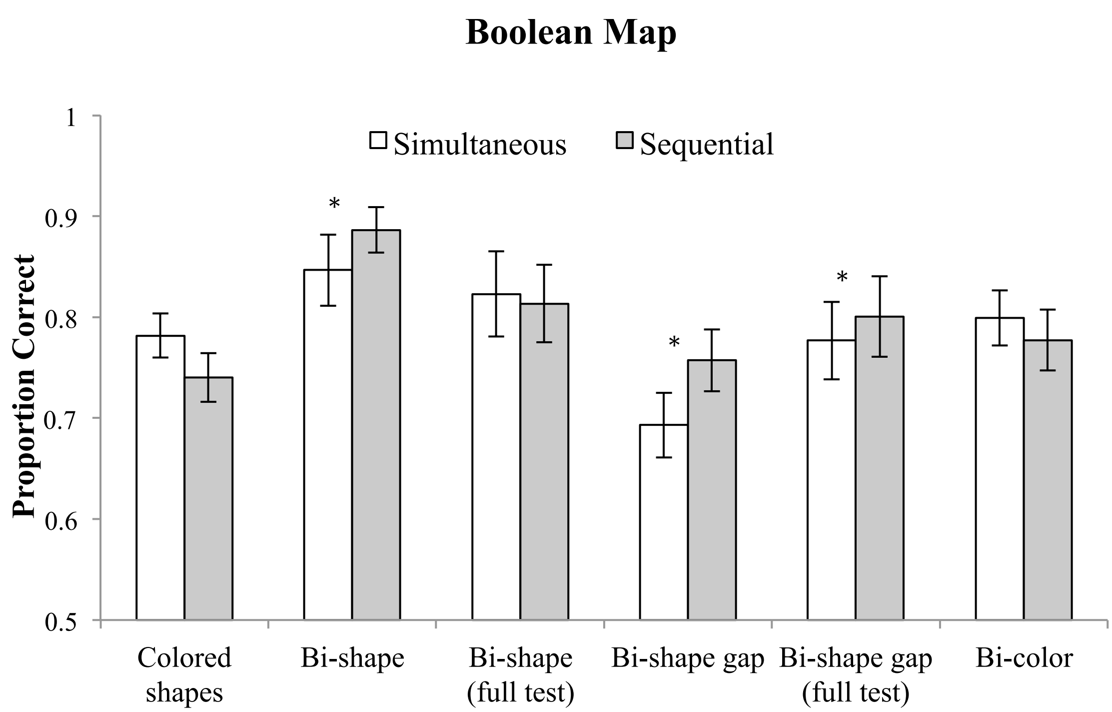


Figure 15. Results of Experiment 2a. Serial access to two features is indicated by greater performance in the sequential condition than the simultaneous condition. Performance was higher in the simultaneous condition thant the sequential conditions in the bi-shape, bi-shape gap, and bi-shape gap full conditions. There was no difference between simultaneous and sequential presentiaton in the colored shape, bi-shape (with full test) and bi-color stimuli. Error bars represent standard error.

Colored shapes. Paired sample t-tests revealed that performance was equal in the sequential presentation ($M = .74$, $SD = .13$) as the simultaneous presentation ($M = .78$, $SD = .14$), $t\,(12) = .97$, $p = .35$, $d = .30$.

Separate analyses were conducted based on whether the test feature was a color or a shape. However, there was no sequential advantage for either test type. When color was tested, there was no difference between simultaneous ($M = .79$, $SD = .16$) and sequential ($M = .74$, $SD = .19$) $t(12) = .10$, $p = .34$. In addition, when shape as tested, there was also no difference between simultaneous ($M = .77$, $SD = .14$) and sequential ($M = .74$, $SD = .15$) $t(12) = .75$, $p = .47$.

Bi-shape (single feature test). Paired sample t-tests revealed that performance was higher with sequential presentation ($M = .89$, $SD = .08$), than simultaneous presentation ($M = .85$, $SD = .07$), $t\,(10) = -5.37$, $p < .001$, $d = .52$.

Bi-shape (full test). Paired sample t-tests revealed that performance was equal with sequential presentation (M = .81, SD = .08) and simultaneous presentation ($M = .82$, $SD = .12$), $t\,(11) = .48$, $p = .64$, $d = .09$.

Bi-shape space (single feature test). Paired sample t-tests revealed that performance was higher with sequential presentation ($M = .76$, $SD = .14$) than simultaneous presentation ($M = .69$, $SD = .15$), $t(12) = -2.26$, $p = .04$, $d = .45$.

Bi-shape space (full test). Paired sample t-tests revealed that performance was higher with sequential presentation (M = .80, SD = .12) than simultaneous presentation ($M = .78$, $SD = .12$), $t(14) = -3.08$, $p = .008$, $d = .20$.

Bi-color. Paired sample t-tests revealed that performance was equal with sequential presentation (M = .85, SD = .08 or, if n = 13, M = .83, SD = .13) and simultaneous presentation ($M = .87$, $SD = .07$ or, M = .84, SD = .11), $t(11) = .34$, $p = .74$, $d = .16$.

Discussion. Experiment 2a revealed several interesting patterns. First, both the color and the shape of the colored shapes were easily accessed in parallel. This is consistent with the prediction of the Boolean map hypothesis that two features from different dimensions can be accessed in parallel.

Second, both features of the bi-shape stimuli were accessed in parallel. When a single feature test was used, there was an advantage for sequential presentation for the bi-shape stimuli. However, when both features were presented at test, there was no sequential advantage. This suggests that it may be difficult to identify the individual shapes of a bi-shape stimulus, but that both shapes are accessed in parallel as a single shape. In contrast, there was no sequential advantage for the bi-shape gap stimuli, regardless of whether a single feature or both features were presented at test. This confirms that when the shapes are split by a small gap, the two shapes are attended serially, regardless of the test type.

Finally, contrary to the expectations of the Boolean map theory (Huang & Pashler, 2007), but consistent with more recent research (Mance et al., 2012), the evidence from Experiment 2a indicates that two different colors were accessed in parallel. The Boolean map hypothesis, therefore, would predict that there should be an object benefit in VWM for colored shapes and bi-shape objects, but no object benefit for bi-shape gap objects.

3.2 Experiment 2b

One assertion of the Boolean map hypothesis is that two identical feature values can be accessed in parallel, while different feature values must be accessed serially. This is important to determine experimentally, because in Experiment 3, it is expected that the object benefit should not occur when feature values are repeated (according to the Boolean map hypothesis). Therefore, in Experiment 2b, the premise that two identical features are accessed in parallel was tested directly with color and shape by comparing the sequential advantage when the two study features were the same to when the two study features were different.

Method.

Design. Experiment 2a utilized a 2 (presentation type) x 2 (feature uniqueness) x 2 (stimulus type) mixed design. Presentation type (simultaneous, sequential) was manipulated within subjects, as was feature uniqueness (same study features, different study features) while stimulus type (shape, color) was manipulated between subjects.

Participants. Thirty-four undergraduate students (24 female, average age = 20.12) participated in this experiment for credit in their undergraduate psychology courses. Eighteen participants were assigned to the 'shape' condition and sixteen to the 'color' condition. Thirty participants reported normal or corrected-to-normal vision and all participants reported normal color vision.

Stimuli and Procedure. The stimuli and procedure were identical to those of the bi-shape and bi-color conditions of Experiment 2a with the following exceptions (see Figure 16). First, in the shape condition, only upright shapes were used. Second, for both the color and shape conditions, the two features were separated by a small gap, even when presented simultaneously. Finally, in half of the trials, the two study features were identical to each other and in the other half, the two study features were different. Within each of these study feature conditions (same, different), the test feature was the same as one of the study features for half of the trials and it was new the other half. When the two study features were different, in half of the 'old' trials, the first feature was tested, while in the other half of the trials, the second feature was tested.

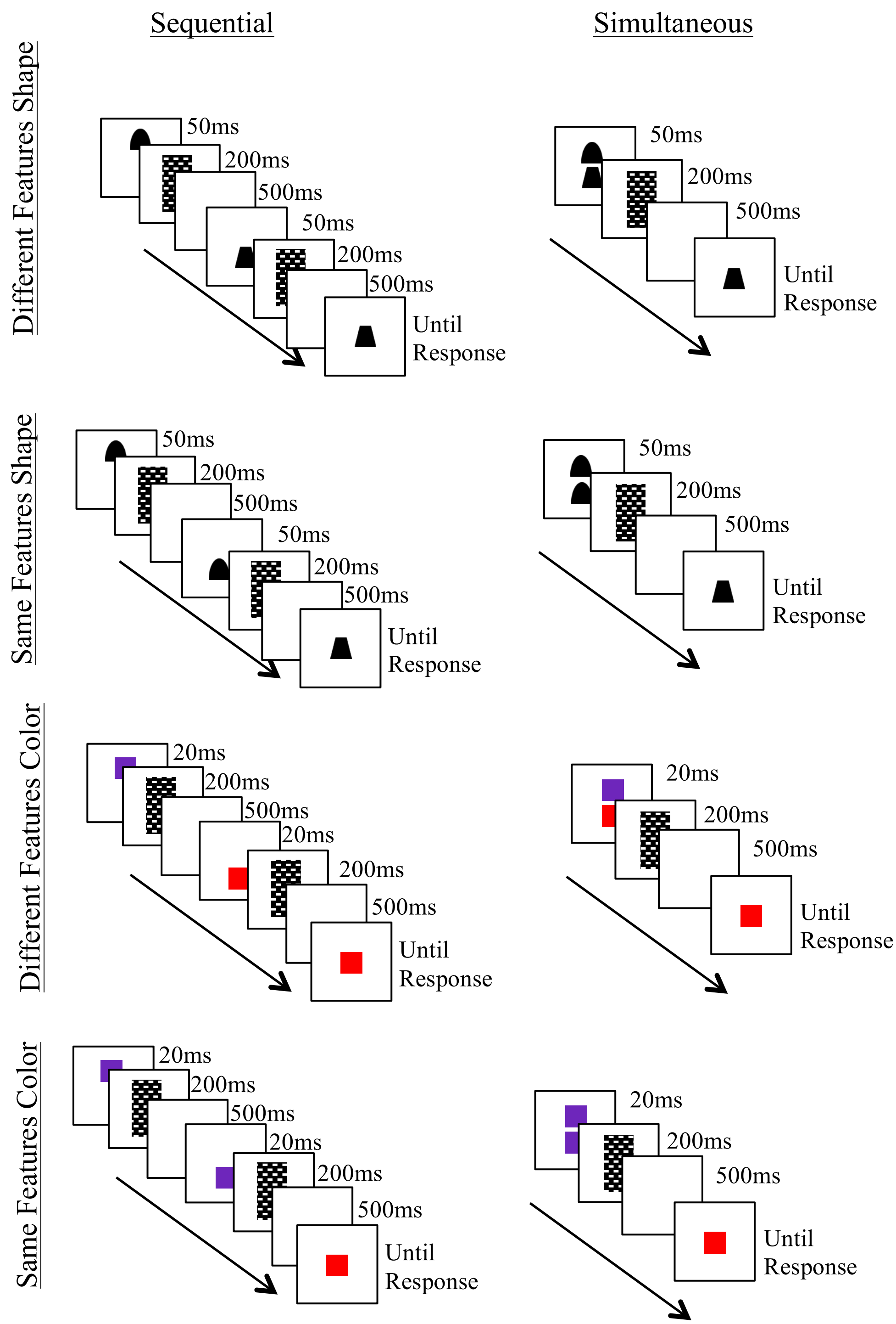


Figure 16. Procedure for Experiment 2b. Participants saw either two study colors or study two shapes. The two study features were either different from one another (unique) or they were the same (repeated). Both "same features" examples show a sample trial in which the correct answer is "new" and both "different feature" examples show a sample trial in which the correct answer is "old."

Results. For both shape and color stimuli, a 2 (feature repetition) x 2 (presentation type) repeated measure ANVOA was conducted with feature repetition (same features or different features) and presentation type (simultaneous or sequential) as within subjects factors (see Figure 17). Planned comparisons directly compared the sequential advantage when the study features were the same and when the study features were different.

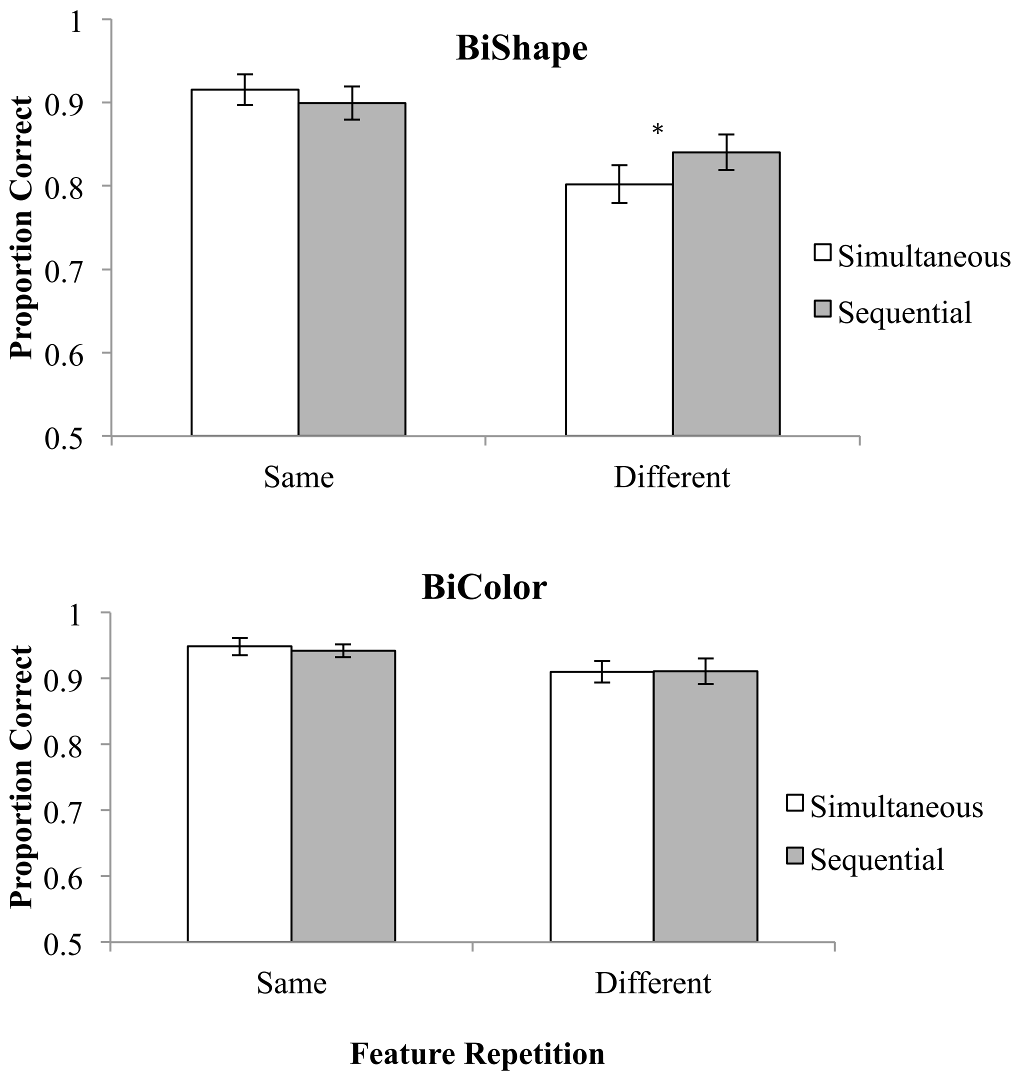


Figure 17. Results of Experiment 2b. Sequential performance was higher than simultaneous performance only in the shape condition, and only when the two study features are different from each other. Error bars represent standard error.

<u>Shape.</u> The results of the shape stimuli show that there was a sequential benefit only when the two study features were different. First, there was no main effect of presentation type, $F(1, 19) = 1.04$, $p = .32$, $\eta^2 = .05$, although there was a main effect of feature repetition, $F(1,19) = 86.81$, $p < .001$, $\eta^2 = .82$, and a significant interaction, $F(1,19) = 8.41$, $p = .009$, $\eta^2 = .79$. Planned comparisons revealed that when both features were the same, performance was marginally higher when presentation was simultaneous ($M = .88$, $SD = .14$) than sequential ($M = .86$, $SD = .14$), $t\ (19) = 1.91$, $p = .07$, $d = .18$. However, when the features were different, there was a sequential benefit: performance was higher when presentation was sequential ($M = .81$, $SD = .14$) than simultaneous ($M = .77$, $SD = .13$), $t(19) = -2.13$, $p = .05$, $d = .41$.

<u>Color.</u> The results of the color stimuli indicate that there was no sequential benefit, regardless of whether the two study features were the same or different. There was no main effect of presentation type, $F(1, 15) = .54$, $p = .48$, $\eta^2 = .03$, although there was a main effect of feature repetition, $F(1,15) = 10.40$, $p = .006$, $\eta^2 = .41$, but no significant interaction, $F(1,15) = .29$, $p = .60$, $\eta^2 = .02$. Planned comparisons revealed that when both features were the same, there was no difference when presentation was simultaneous ($M = .93$, $SD = .11$) or sequential ($M = .91$, $SD = .12$), $t\ (15) = 1.11$, $p = .28$, $d = .11$. In addition, when the feature values were different, performance was the same when the presentation was sequential ($M = .88$, $SD = .13$) as simultaneous ($M = .89$, $SD = .11$), $t(15) = .22$, $p = .83$, $d = .01$.

Discussion. Consistent with the premise that two identical feature values from the same dimension can be accessed in parallel, the results of Experiment 2b showed that two identical shapes could be accessed in parallel, while two different shapes must be accessed serially. This suggests that shape features operate like orientation (Lui & Becker, in press) and different shape value must be accessed serially, and therefore represented on separate maps. However, in the color condition, there was no sequential advantage, regardless of whether the colors were the same or different (although overall performance was higher when the colors were the same). This suggests that up to two color values can be accessed in parallel, contrary to the results of Huang and Pashler (2007), but consistent with Mance et al., (2012), who found that four colors were accessed serially, but participants could access two colors in parallel.

Because two identical shape values can be accessed in parallel, but two different shape values must be accessed serially, the results of Experiment 2b support the premise for Experiment 3 that two identical feature values (in the shape dimension) can be represented on the same map. This suggests that the object benefit in VWM will depend on whether or not there are repeated feature values in an array. For example, in an array that contains two single-featured objects, two Boolean maps will be created. In contrast, an array that contains one bi-featured object will result in the creation of one map, as will an array that contains two identical single featured objects. Therefore, if the two feature values are unique, then there will be an object benefit in VWM: performance will be better if the two feature values are combined into a single object. In contrast, if the two feature values are identical, then there will be no object benefit: performance will be the same when there are two objects and when there is one object.

CHAPTER 4. EXPERIMENT 3: THE OBJECT BENEFIT

Experiment 3 tested the object benefit in VWM for colored shapes, bi-color stimuli, bi-shape stimuli, and bi-shape gap stimuli. This study utilized a change detection task: memory arrays contained either three objects or six objects. In the three-object arrays, each object consisted of two features (the conjunction condition). In the six-object arrays, each object consisted of only a single task relevant feature (the disjunction condition). Therefore, in both the conjunction and disjunction condition, participants were required to remember six features in order to accurately complete the task. However, in the conjunction condition, there were only three objects, while in the disjunction condition, there were six objects. An object benefit is revealed if performance is higher in the conjunction condition than the disjunction condition.

This study also manipulated whether all of the features in the display were unique (e.g., there would never be two 'blue' stimuli) or whether features in a display were repeated (e.g., there could two blue stimuli present). The reason for this manipulation is that, according to the Boolean map hypothesis, two identical features can be represented on the same Boolean map. This was supported by Experiment 2b, in which it was demonstrated that two identical shape values could be accessed in parallel, while two different shape values must be accessed serially. Therefore, the object benefit should only exist when feature values are unique. Combining two features into a single object serves the same purpose: integrating two features into the same map. Therefore, when feature values are repeated, the object benefit should be eliminated. In contrast, the object hypothesis predicts that the object benefit should be the same regardless of whether the feature values are unique or repeated. To test this prediction, the object benefit will be examined when feature values are unique and when feature values are repeated.

4.1 Method

Design. Experiment 3 utilized a 2 (conjunction) x 2 (feature uniqueness) x 4 (stimulus type) mixed design. Conjunction (conjunction, disjunction) was manipulated within subjects, as was feature uniqueness (unique, repetition) while stimulus type (colored shape, bi-shape, bi-shape gap, bi-color) was manipulated between subjects.

Participants. Ninety-five undergraduate students participated in this experiment for credit in their undergraduate psychology courses (72 female, average age = 20.29). All students reported normal color vision and 88 reported normal or corrected to normal vision. Twenty-one students were assigned to the colored shape condition, 22 to the bi-shape condition, 26 were assigned to the bi-shape gap condition, and 26 to the bi-color condition.

Stimuli. Experiment 3 utilized the colored shapes, bi-shape, bi-shape gap, and bi-color stimuli from Experiments 1 and 2a. For each stimulus type, study arrays were created that contained a total of six features. These features were either separated into six objects (disjunction condition) or combined into three objects (conjunction condition; see Figure 18). In addition, the features in the array were either all unique, or some of the feature values were repeated. When feature values were repeated, the feature combinations were restricted so that, in the conjunction condition, no two identical objects could appear (e.g., there may be a red oval, a green cross, and a red cross, but there could not be two green crosses). In the bi-shape condition, a 'top' and 'bottom' were never the same shape. That is, a cross would not be present both as upright and inverted. This was also true of the color condition: green, for example, would not appear both as a top and bottom color. This way, two identical features could not be combined into a single object.

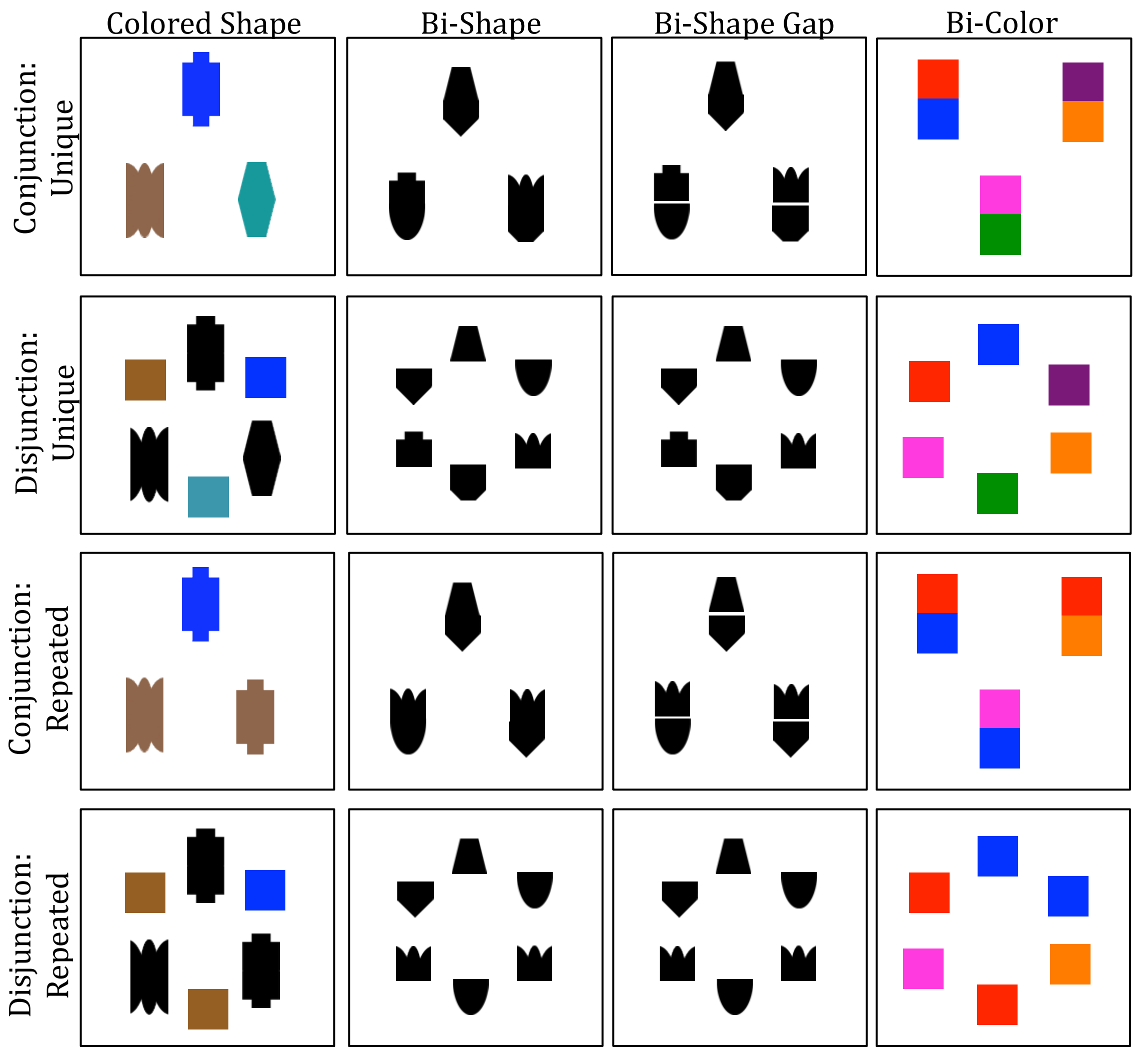


Figure 18. Array types for Experiment 3. Each stimulus type is shown in the columns: colored shapes, bi-shape, bi-shape space and bi-color. Each row shows a different repeated and conjunction conditions.

Objects were arranged in a circle in a total of six possible locations, corresponding to the 12:00, 2:00, 4:00, 6:00, 8:00, and 10:00 positions on a clock. In the conjunction condition, there were two possible stimulus arrangements that were randomly intermixed. Either a single object appeared on top (corresponding to the 12:00 position), with two objects on the bottom (the 4:00 and 8:00 position), or two objects appeared on the top (corresponding to the 10:00 and 2:00

positions on a clock), with a single object on the bottom (the 6:00 position). In the disjunction condition, a single feature appeared in each of the possible locations.

Test arrays were either identical to the study array, or one of the features changed from study to test. In the bi-color condition, when a change occurred, only one colored square would change color. In the bi-shape condition, when a change occurred, only one shape would change (i.e., either a top or bottom shape would change, but not both). In the colored shape condition, the participants would detect changes to either shape or color.

Procedure. Participants viewed a study array of three (conjunction condition) or six (disjunction condition) objects for 500 ms (see Figure 19). This was followed by a 800ms blank screen interstimulus interval (ISI), then a test array of objects (see Figure 19). Half of the time, the test array was identical to the study array and half the time one of the features changed. Participants indicated whether they saw a change or no change by pressing ‘z’ or ‘/’ on a keyboard (256 trials; half change and half no-change). In the colored shape condition, there were twice as many trials (512) so that color and shape performance could be analyzed separately. In the disjunction condition, participants were instructed that the black shapes might changes shape and the colored squares might change color, whereas in the conjunction condition, any stimulus might change shape or color.

For each participant, there were four total conditions: unique-conjunction, unique-disjunction, repeated-conjunction, and repeated-disjunction. All four conditions were completed in separate blocks, and the order of the blocks was counterbalanced across participants.

Before the experiment began, participants completed an instruction phase similar to that in Experiment 2. Participants saw figures with procedures of all possible trial types and indicated what the correct answer for that trial type would be. Participants received feedback about their responses and only moved to the experimental phase after they correctly identified the response to all instruction trials.

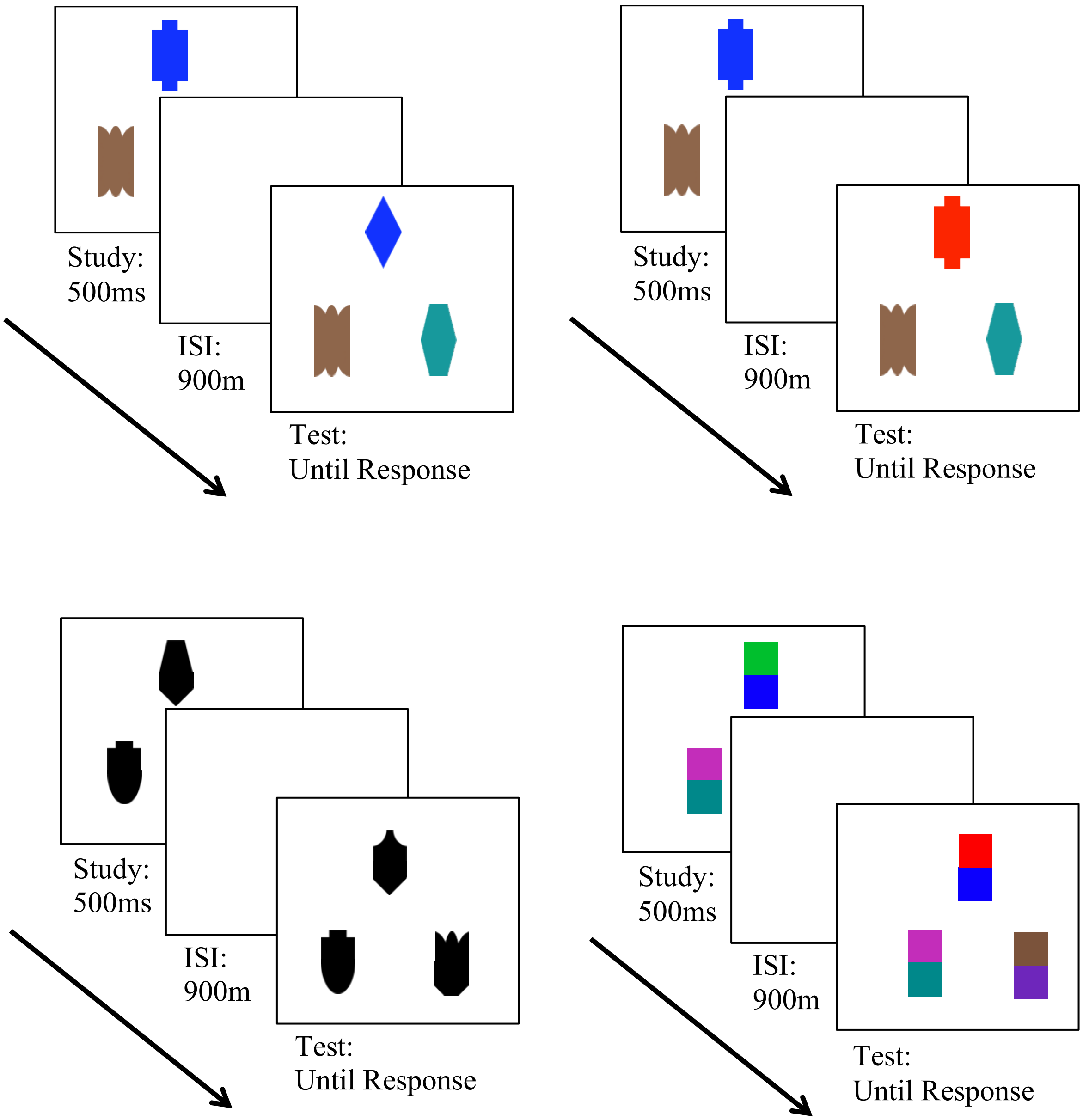


Figure 19. Procedure for Experiment 3. This figure shows an example of the procedure for the change detection task. All four examples illustrate trials in which the correct answer is ‘change.’ The top two examples show a color change and a shape change for the colored shapes and the bottom two examples demonstrate shape change for the bi-shape stimuli, and a color change for the bi-color stimuli. All four examples show the conjunction condition.

Before each block, participants completed 8 practice trials; half were change and half were no change. In the bi-shape, bi-shape gap, and bi-color conditions, participants completed 64 trials in each block (half change and half no-change), for a total of 256 trials. In the colored shape condition, participants completed twice as many trials (128 in each block), so that there were a sufficient amount of trials for shape and color performance to be analyzed separately. In the colored shape condition, half of the changes were shape changes and half were color changes.

4.2 Results

The object benefit was measured as higher performance in the conjunction condition versus the disjunction condition. For each stimulus type, the object benefit was measured: 1) when feature values were unique and 2) when feature values were repeated. Planned comparisons specifically compared performance in the conjunction condition to performance in the disjunction condition first when features were unique, and then when feature values were repeated (see Figure 20).

Unique features. When feature values were unique, there was an object benefit for colored shapes $t(18) = 5.25$, $p < .001$, $d = 1.11$, and bi-shape stimuli $t(21) = 3.58$, $p = .002$, $d = .61$ only. There was no object benefit for the bi-shape gap stimuli $t(25) = 1.44$, $p = .16$, $d = .31$ or bi-color stimuli $t(25) = .52$, $p = .60$, $d = .09$.

In addition, in the colored shape condition, performance on the color-change trials and the shape-change trials were analyzed separately, so that the objet benefit could be tested for each change type. Because the no-change trials did not contain any indication about what type of change might occur, only change trials were analyzed. An object benefit was found both for color changes, $t(20) = 3.40$, $p = .003$, $d = .57$, and shape changes $t(20) = 4.39$, $p < .001$, $d = .85$.

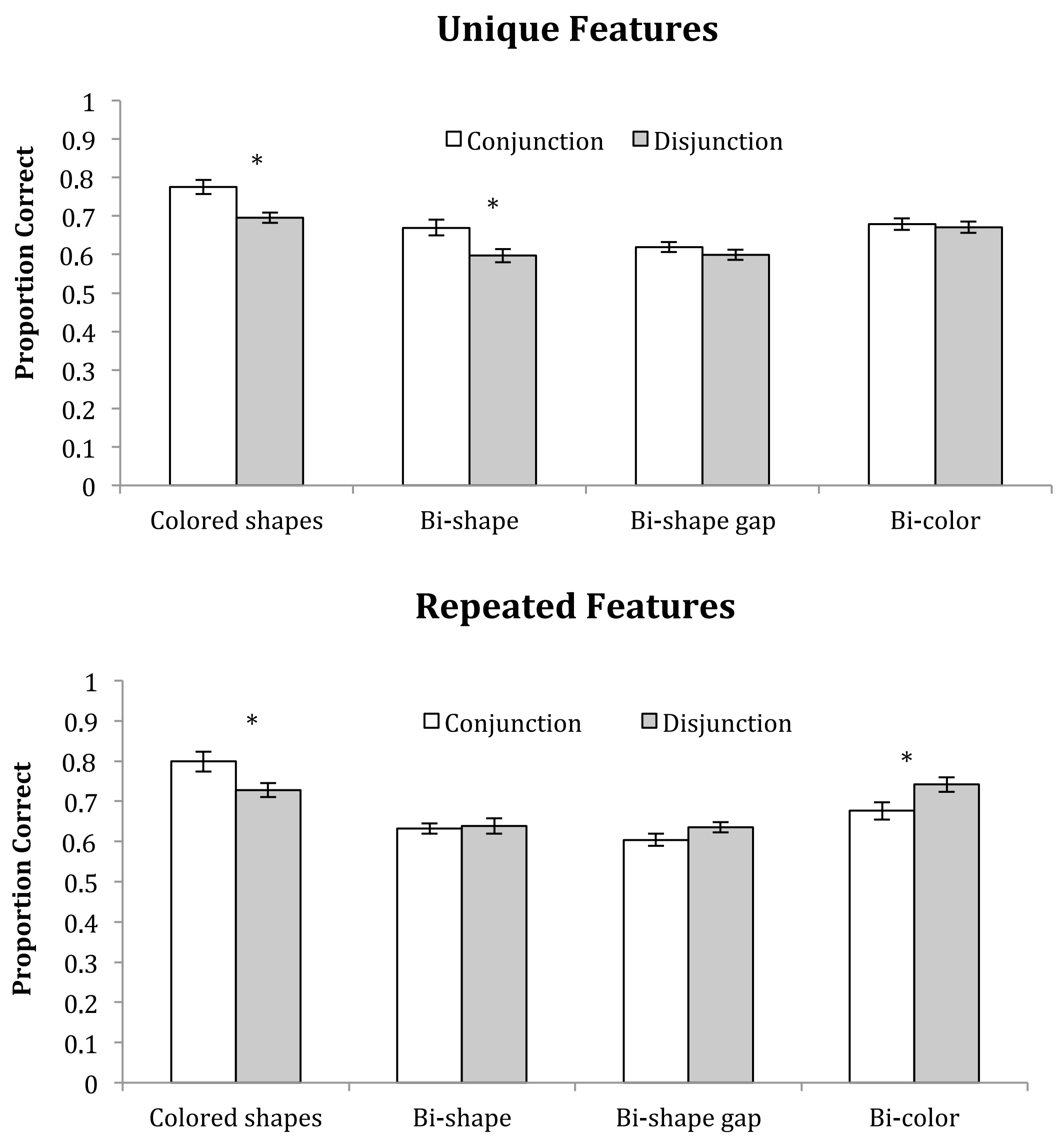


Figure 20. Results of Experiment 3. Asterisks indicate a significant difference between the conjunction and disjunction conditions. These results showed that there was an object benefit for colored shapes when features were unique and when features were repeated. However, the object benefit occurred for bi-shape stimuli only when features were unique. In addition, there was a disjunction benefit for bi-colored stimuli when features were repeated. Error bars represent standard error.

Repeated features. When feature values were repeated, there was an object benefit for colored shapes only $t(18) = 4.25$, $p < .001$, $d = .73$; this benefit occurred for both color changes $t(20) = 2.32$, $p = .03$, $d = .39$, and shape changes $t(20) = 4.58$, $p < .001$, $d = 1.27$. There was no object benefit for bi-shape stimuli $t(21) = -.34$, $p = .74$, $d = .07$, or bi-shape gap stimuli $t(25) = -1.68$, $p = .11$, $d = .43$. For the bi-color stimuli, performance was actually higher in the disjunction condition than the conjunction condition $t(25) = -2.62$, $p = .02$, $d = .64$.

4.3 Discussion

The results of Experiment 3 supported previous research and indicated several new findings. First, an object benefit occurred in the colored shapes condition, which is consistent with previous research (Luria & Vogel, 2011; Olson & Jiang, 2002; Xu, 2002). In addition, the object benefit in the colored shape condition occurred regardless of whether feature values were unique or repeated.

Second, no object benefit existed for the bi-color stimuli, also consistent with previous research (Olson & Jiang, 2002; Wheeler & Treisman, 2002; Xu, 2002). Not only was there no object benefit, but when feature values were repeated, performance was better in the disjunction condition. This is likely because putting two features together into an object encourages participants to attend to these stimuli as objects. For example, the bi-color stimuli showed an effect of object-based attention (Experiment 1), which suggests that participants can group both colors of a bi-shape stimulus together as an object. However, grouping two different color values together as a single object may prevent participants from grouping two identical feature values from different objects together onto the same Boolean map. This suggests that consideration of stimuli as objects does affect how the objects are attended and subsequently remembered, but not always in a way that maximizes capacity.

In addition, there was an object benefit in the bi-shape condition, but only when feature values were unique. This supports Kim and Kim (2011), who found an object benefit with two shapes, and suggests that the lack of object benefit for color is not because two features from the same dimension cannot benefit by combining them into a unified object, but rather this difficulty may occur for colors specifically. However, when feature values were repeated, there was no object benefit. This supports the Boolean map hypothesis, and suggests that repeated feature values can be represented on the same map, eliminating the benefit caused by integrating the two features into a unified representation. This is consistent with the results of Experiment 2b, which showed that two identical shapes are accessed in parallel, and the results of Experiment 2a, which showed that two shapes combined into a new shape can be accessed in parallel.

Finally, there was no object benefit for the bi-shape gap stimuli, either when the features were unique or when they were repeated. This is also consistent with the Boolean map hypothesis because the two shapes of the bi-shape gap stimuli are accessed serially (Experiment 2a) even if those two shapes can be attended as an object (Experiment 1).

Finally, Experiment 3 indicated that repeating feature values has a significant impact on the object benefit for the bi-shape stimuli, a pattern not predicted by a strict object hypothesis. Rather, the presence of other objects features affects how individual items are represented in VWM (Brady & Tenenbaum, 2012). In this experiment, repeating feature values reduced the likelihood that an object benefit would occur, likely because two identical features can be represented together.

CHAPTER 5. GENERAL DISCUSSION

Overall, the results of this study support the Boolean map hypothesis over the object hypothesis (see Figure 21). That is, the representation of visual information is not strictly object-based, but rather, a representation that is sensitive both to objects and features (a Boolean map). While objects composed of two colors, two shapes, or one color and one shape can all be selected for attention as objects (Experiment 1), both features are not necessarily stored together in VWM (Experiment 3). This suggests that a different unit of representation may better describe how information is maintained in VWM. Specifically, Boolean maps, which have been proposed as a unit of attention, have both object and feature qualities that better describe a variety of results from VWM tasks. In addition, Boolean maps can also account for the way that the presence of other features can change how information is represented in VWM.

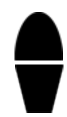
	 *Colored Shape*	 *Bi-Shape*	 *Bi-Shape Space*	 *Bi-Color*
Object-Based Attention (Experiment 1)	✓	✓	✓	✓
Number of Boolean Maps (Experiment 2)	1	1	2	1
Object Benefit in Memory *Unique Features* (Experiment 3)	✓	✓	✗	✗
Object Benefit in Memory *Repeated Features* (Experiment 3)	✓	✗	✗	✗
Hypothesis Supported	Object and Boolean Map	Boolean Map	Boolean Map	Neither

Figure 21. Conclusions of the current study. Overall, the results support the predictions of the Boolean map hypothesis over the object hypothesis, although the results for the bi-color stimuli are somewhat ambiguous.

The results of the bi-shape and bi-shape gap stimuli offer a unique insight into the way that two features from the same dimension (shape) can be combined into a unified representation, affecting how that information is remembered in VWM. Object-based attention was revealed for both the bi-shape and the bi-shape gap stimuli (Experiment 1). This suggests that object-based attention can operate over stimuli that are connected by grouping cues, such as proximity, and that a uniform surface feature is not required to attend to stimuli as an object (Marino & Scholl, 2005). When the grouping principle was violated (separated condition), there was no longer an object-based spread of attention. However, even though two features can be grouped together and selected as a unit for attention, this does not necessarily mean those two features will be represented together in VWM. Specifically, there was an object benefit for the bi-shape stimuli, but not the bi-shape gap stimuli (Experiment 3). This suggests that a small gap between the shape features was sufficient to prevent the two features from being represented together in VWM (as indicated by an object benefit). However, the object hypothesis predicted that the object benefit in VWM should occur for bi-shape gap stimuli, because these stimuli showed object-based attention in Experiment 1. Furthermore, the object benefit was eliminated for the bi-shape stimuli when there were repetitions of individual features in the array. The Boolean map hypothesis predicts this pattern, as identical features can be stored together on the same Boolean map.

The colored shape stimuli offer an instance in which the proposed number of objects and the proposed number of Boolean maps are the same. Consequently, both hypotheses predict an object benefit in VWM, which was found in Experiment 3. In addition, colored shapes showed an object-based spread of attention (Experiment 1), and both the features (color and shape) can be accessed by the observer in parallel (Experiment 2). However, the colored shape stimuli also demonstrated an object benefit when features were repeated, which did not occur for the bi-shape stimuli. This finding highlights one aspect of the Boolean map hypothesis that is currently not well defined. Specifically, is the limit on the number of Boolean maps fixed, or is the limit on the number of maps flexible, depending on the load introduced by each map? Do some maps consume more capacity than others? This question has been addressed in the VWM literature from the object perspective: objects that are more 'complex' may consume more capacity than others (Alvarez & Cavanaugh, 2004; Eng et al., 2005). At this point in the development of the Boolean map hypothesis, it is unclear whether a map that locates multiple objects (e.g., the locations of two red features) would consume the same amount of resources as a map that located a single object composed of two different feature dimensions.

Previous research suggests that, memory is better when the color and shape of an object belong to the same 'part' (Xu, 2002a). This suggests that integrating features from different dimensions into a unified representation has a benefit that is greater than simply adjoining two features. It has been suggested that remembering colored shapes is more similar to remembering a unidimensional object than remembering multiple features of a multidimensional object (Morey & Bieler, 2012). That is, the complete integration of color and shape into a single object is so powerful that remembering both the color and shape functions more like remembering a single feature than remembering two features. This may be why there is an object benefit for the colored shape stimuli, even when features were repeated. It is likely that the integration of the two features into a single representation is not all-or-none, but graded, depending on the stimulus characteristics (such as the number of parts and whether the features are from the same or different dimensions). This integration is likely more robust when the two features come from different dimensions.

Support for this idea can be seen in Experiment 1: the magnitude of object-based attention (that is, the between object RT cost minus the within object RT cost) was much greater for the colored shapes (57ms) than any of the other stimuli. The stimulus type with the next highest object-based attention magnitude was the bi-shape stimuli, at 27ms (independent samples t-tests show these two stimuli differed significantly: $t(43) = 3.20$, $p = .003$). This suggests that the colored shape condition may represent the most complete integration of two features into a single representation. Therefore, integrating a shape and a color into a single object may maximize capacity more than repeating identical feature values of a single dimension. This hypothesis, however, requires additional research to confirm, although it is possible within both the object-based and Boolean map-based frameworks. Regardless of whether VWM stores objects or Boolean maps, integrating a color and a shape into a single representation has a greater effect on memory than integrating two shapes into a single representation; the reasons for why this might be require additional research.

In terms of the cost to capacity in VWM, creating a map that includes both the color and the shape of a single unified object may operate more like remembering a single red square on a map, rather than remembering two red squares on a single map. To test this hypothesis, an experiment could be conducted that combines the colored squares of the bi-shape condition and the shapes of the bi-shape condition. Rather than combining the color and shape to create an integrated object, a colored square and shape feature can be joined (as in the bi-shape and bi-color conditions) to create a multi-featured, multi-part object. In this way, the benefit of just combining two features from different dimensions into a single object can be compared to the benefit of creating an integrated representation. In this proposed experiment, it might be expected that a conjunction benefit should occur only when features are unique. More research is needed to test this hypothesis, but this may offer more insight into the way that features are integrated into unified representations in VWM.

The results of the bi-color stimuli are more ambiguous than those of the bi-shape or colored shape stimuli. While object-based attention did operate over the bi-color stimuli (Experiment 1) and two colors were accessed in parallel (Experiment 2), there was no object benefit for bi-color stimuli (Experiment 3). In addition, when feature values were repeated in Experiment 3, performance was higher in the disjunction condition than in the conjunction condition, the opposite of an object benefit. This suggests that participants are able to group together two identical feature values together in the same representation (consistent with the Boolean map hypothesis), but that combining two different features (e.g., red and blue) into a single object disrupts this process, suggesting that both repeating feature values and grouping features into objects affect memory. However, the results of Experiment 2 showed that two different colors could be accessed in parallel, which does not support the Boolean map hypothesis. One possibility for why there was no sequential benefit for color in Experiment 2 may be that the stimuli used in this study differed too much from the original Huang and Pashler (2007) stimuli. Specifically, in this study, the stimuli were presented as two stacked colors. In Huang and Pashler (2007), the two tested colors were placed on diagonal quadrants (see Figure 6) and the stimuli themselves were much larger. Using the colors in this study, a follow-up experiment was run in which the colored squares were placed in quadrants, and the squares were also enlarged; a small but significant sequential benefit was found. Mance et al. (2012) also found that there was no sequential benefit for two colors, although they did find a sequential benefit for four colors. They concluded that up to two colors can be accessed in parallel. If this is the case, it is possible that in Experiment 2, both colors were accessed in parallel, but in

Experiment 3, when there were up to six unique colors, a serial strategy was forced. More research is therefore required to examine the exact nature of how multiple colors are accessed and subsequently stored in VWM.

One advantage of the Boolean map hypothesis is that both features and objects are important in determining capacity limits. In addition, within an object, there are different effects for two features that are part of the same dimension and features that come from different dimensions. Given that all of these factors have been shown to affect memory (Luck & Vogel, 1997; Olson & Jiang, 2002; Wheeler & Treisman, 2002), the Boolean map hypothesis offers a potential way of integrating the previous literature that have, until now, supported different hypotheses. In addition, the Boolean map hypothesis may be able to incorporate results that demonstrate that higher-order statistics affect memory (e.g., if there are a lot of large blue dots, participants will remember a small blue dot as larger; Brady & Alvarez, 2011), or change detection performance is better when there are multiple objects with features that can be grouped together (Brady & Tenenbaum, 2012). Results such as these suggest that a mechanism in which individual objects are remembered independently from one another is incomplete. However, the Boolean map hypothesis recognizes that shared features connect individual objects. In addition, it is more flexible than object-based or feature-based storage systems, as it allows the observer to select whether individual features or objects are represented, consistent with research that shows participants are able to bias VWM toward more task-relevant information (van Lamsweerde & Beck, 2011; van Lamsweerde & Beck, in preparation). More research is necessary to develop a complete model regarding the way that higher-order information may be represented on a Boolean map, but its inherent flexibility makes it a good candidate for a framework in which to develop hypotheses regarding the way that more complex information may be remembered.

If additional research supports the hypothesis that a Boolean map is a more accurate depiction of the way that information is remembered in VWM than objects or features, several additional questions are still open regarding the structure of VWM. One point alluded to already is capacity limits. How many maps can be remembered (Luck & Vogel, 1997)? Is the number of maps that can be remembered fixed or flexible (Alvarez & Cavanaugh, 2004)? Do some maps consume more capacity than others? Does the precision of the information on the maps decrease as the amount of information increases (Bays & Husain, 2008)? While these questions are still open ended, the Boolean map hypothesis offers a unique way of integrating previously divided research, as it offers a flexible system that is sensitive to both the number of objects and features, as well as a unit of representation that allows for the influence of context in the representation of individual items.

The results of this study offer a new way of viewing the unit of representation in VWM. Specifically, the unit of representation is likely one that is more flexible than strictly object or feature based. Capacity can be maximized by representing multiple features in a single object (indicating a more object-based representation), or by representing identical features together in a single representation (suggesting a more feature-based representation). This study suggests that these two strategies are not necessarily in conflict. Rather, both of these strategies may work within a single representational format. The Boolean map offers a method of conceptualizing such a representational format, which allows the observer to flexibly determine which visual information to maintain in VWM.

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APPENDIX A: IRB APPROVAL FOR EXPERIMENTS 1 AND 2

Unless qualified as meeting the specific criteria for exemption from Institutional Review Board (IRB) oversight, ALL LSU research/ projects using living humans as subjects, or samples, or data obtained from humans, directly or indirectly, with or without their consent, must be approved or exempted in advance by the LSU IRB. This Form helps the PI determine if a project may be exempted, and is used to request an exemption.

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– Applicant,Please fill out the application in its entirety and include the completed application as well as parts A-E, listed below, when submitting to the IRB. Once the application is completed, please submit two copies of the completed application to the IRB Office or to a member of the Human Subjects Screening Committee. Members of this committee can be found at http://research.lsu.edu/CompliancePoliciesProcedures/InstitutionalReviewBoard%28IRB%29/item24737.html

– A Complete Application Includes All of the Following:
(A) Two copies of this completed form and two copies of part B thru E.
(B) A brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts 1&2)
(C) Copies of all instruments to be used.
*If this proposal is part of a grant proposal, include a copy of the proposal and all recruitment material.
(D) The consent form that you will use in the study (see part 3 for more information.)
(E) Certificate of Completion of Human Subjects Protection Training for all personnel involved in the project, including students who are involved with testing or handling data, unless already on file with the IRB. Training link: (http://phrp.nihtraining.com/users/login.php)
(F) IRB Security of Data Agreement: (http://research.lsu.edu/files/item26774.pdf)

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*If student, please identify and name supervising professor in this space
Melissa Beck, Psychology, Professor, (225) 578-7214, mbeck@lsu.edu

IRB# E6033 LSU Proposal #______
Complete Application
Human Subjects Training

3) Project Title: Visual attention for objects

Study Exempted By:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
203 B-1 David Boyd Hall
225-578-8692 I www.lsu.edu/irb
Exemption Expires: 7/8/2015

4) Proposal? (yes or no) N **If Yes, LSU Proposal Number**

Also, if YES, either
This application completely matches the scope of work in the grant
OR
More IRB Applications will be filed later

5) Subject pool (e.g. Psychology students) Psychology Students
*Circle any **"vulnerable populations" to be used**: (children <18; the mentally impaired, pregnant women, the ages, other). Projects with incarcerated persons cannot be exempted.

6) PI Signature [signature] **Date** 6/28/12 (no per signatures)

** **I certify my responses are accurate and complete.** If the project scope or design is later changes, I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted. I also understand that it is my responsibility to maintain copies of all consent forms at LSU for three years after completion of the study. If I leave LSU before that time the consent forms should be preserved in the Departmental Office.

Screening Committee Action: Exempted √ Not Exempted ____ Category/Paragraph 2

Reviewer Mathews **Signature** [signature] **Date** 7/9/12

Study Exempted By:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
203 B-1 David Boyd Hall
225-578-8692 | www.lsu.edu/irb
Exemption Expires: 7/8/2015

Consent Form

1. Study Title: Visual attention for objects

2. Performance Site: Louisiana State University

3. Investigators: The following investigators are available for questions about this study
Amanda E. van Lamsweerde: avanla1@tigers.lsu.edu

4. Purpose of the Study: The purpose of this project is to investigate how attention can be allocated across objects.

5. Subject Inclusion: Individuals between the ages of 18 and 65 with normal or corrected-to normal vision.

6. Number of subjects: 200

7. Study Procedures: The study will take approximately 60 minutes. Participants will be asked to look at pictures on a computer screen and will answer questions about the pictures.

8. Benefits: The data collected from the study will further research regarding visual attention.

9. Risks: There are no known risks associated with this study.

10. Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which they might otherwise be entitled.

11. Privacy: Results of the study may be published, but no names or identifying information will be included in the publication. Subject identity will remain confidential unless disclosure is required by law.

12. Signatures: The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board,(225) 578-8692. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of this consent form.

Subject Signature:______________________________ Date:____________________

APPENDIX B: IRB APPROVAL FOR EXPERIMENT 3

Application for Exemption from Institutional Oversight

Unless qualified as meeting the specific criteria for exemption from Institutional Review Board (IRB) oversight, ALL LSU research/ projects using living humans as subjects, or samples, or data obtained from humans, directly or indirectly, with or without their consent, must be approved or exempted in advance by the LSU IRB. This Form helps the PI determine if a project may be exempted, and is used to request an exemption.

LSU
Institutional Review Board
Dr. Robert Mathews, Chair
131 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu
lsu.edu/irb

– Applicant,Please fill out the application in its entirety and include the completed application as well as parts A-F, listed below, when submitting to the IRB. Once the application is completed, please submit two copies of the completed application to the IRB Office or to a member of the Human Subjects Screening Committee. Members of this committee can be found at http://research.lsu.edu/CompliancePoliciesProcedures/InstitutionalReviewBoard%28IRB%29/item24737.html

– A Complete Application Includes All of the Following:
- **(A)** Two copies of this completed form and two copies of parts B thru F.
- **(B)** A brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts 1&2)
- **(C)** Copies of all instruments to be used.
  - *If this proposal is part of a grant proposal, include a copy of the proposal and all recruitment material.
- **(D)** The consent form that you will use in the study (see part 3 for more information.)
- **(E)** Certificate of Completion of Human Subjects Protection Training for all personnel involved in the project, including students who are involved with testing or handling data, unless already on file with the IRB. Training link: (http://phrp.nihtraining.com/users/login.php)
- **(F)** IRB Security of Data Agreement: (http://research.lsu.edu/files/item26774.pdf)

1) Principal Investigator: Amanda E. van Lamsweerde **Rank:** Graduate Student

Dept: Psychology **Ph:** (949) 533-6319 **E-mail:** avanla1@lsu.edu

2) Co Investigator(s): please include department, rank, phone and e-mail for each
*If student, please identify and name supervising professor in this space
Melissa R. Beck, Professor, (225) 578-7214, mbeck@lsu.edu

IRB# E7087 LSU Proposal # ______
✓ Complete Application
✓ Human Subjects Training

3) Project Title: Memory for objects and parts

Study Exempted By:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
203 B-1 David Boyd Hall
225-578-8692 | www.lsu.edu/irb
Exemption Expires: 10/16/2015

4) Proposal? (yes or no) No **If Yes, LSU Proposal Number** ______

Also, if YES, either
○ **This application completely matches the scope of work in the grant**
OR
○ **More IRB Applications will be filed later**

5) Subject pool (e.g. Psychology students) Psychology Students

*Circle any **"vulnerable populations" to be used:** (children <18; the mentally impaired, pregnant women, the ages, other). Projects with incarcerated persons cannot be exempted.

6) PI Signature Amanda van Lamsweerde **Date** 10/12/12 (no per signatures)

**** I certify my responses are accurate and complete.** If the project scope or design is later changes, I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted. I also understand that it is my responsibility to maintain copies of all consent forms at LSU for three years after completion of the study. If I leave LSU before that time the consent forms should be preserved in the Departmental Office.

Screening Committee Action: Exempted ✓ Not Exempted ____ Category/Paragraph 2

Signed Consent Waived?: Yes / No

Reviewer Mathews **Signature** Robert C Mathews **Date** 10/17/12

Study Exempted By:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
203 B-1 David Boyd Hall
225-578-8692 | www.lsu.edu/irb
Exemption Expires: 10/16/2015

Consent Form

1. Study Title: Memory for Objects and Parts

2. Performance Site: Louisiana State University

3. Investigators: The following investigators are available for questions about this study
   Amanda E. van Lamsweerde: avanla1@tigers.lsu.edu

4. Purpose of the Study: The purpose of this project is to investigate how attention is related to memory for objects and parts of objects.

5. Subject Inclusion: Individuals between the ages of 18 and 65 with normal or corrected-to normal vision.

6. Number of subjects: 100

7. Study Procedures: The study will take approximately 60 minutes. Participants will be asked to look at pictures on a computer screen and will answer questions about their perception and memory of the objects on the screen. Participants will be asked to make judgments about words while completing a visual memory task.

8. Benefits: The data collected from the study will further research regarding visual attention and memory.

9. Risks: There are no known risks associated with this experiment.

10. Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which they might otherwise be entitled.

11. Privacy: Results of the study may be published, but no names or identifying information will be included in the publication. Subject identity will remain confidential unless disclosure is required by law.

12. Signatures: The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board,(225) 578-8692. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of this consent form.

Subject Signature:________________________________ Date:____________________

VITA

Amanda Elaine van Lamsweerde was born in Valencia, California to parents Deborah Craig and Carl van Lamsweerde. She graduated magna cum laude in 2006 from the University of California, Irvine with her B.A. in Psychology. She attended Louisiana State University in 2007 under the supervision of Dr. Melissa Beck and earned her M.A. in Psychology in 2010. She will complete her PhD in Psychology from Louisiana State University in 2013.