# FLEXIBILITY IN OBJECT-BASED SELECTION

BY

AUDREY GARDNER LUSTIG

DISSERTATION

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Doctoral Committee:

Associate Professor Diane Beck, Chair
Professor Monica Fabiani
Professor Wendy Heller
Associate Professor Alejandro Lleras
Professor Daniel Simons

## ABSTRACT

A well established finding in the field of visual attention is that attention tends to operate in an object-based manner (i.e., all features of attended objects, including task-irrelevant ones, tend to be co-selected, e.g., O'Craven et al.). However, recent evidence suggests that object-based attention is not always obligatory; people can be pushed into prioritizing one object feature over another. The goal of the current study was to test the hypothesis that people can attend to multidimensional objects in a flexible manner even when there is no explicit benefit, and that this tendency varies across people. To test this idea, we ran four experiments using a priming of pop-out task in which participants searched for multidimensional targets (containing orientation and color). Orientation was always the target-defining and thus task-relevant feature, while color was always irrelevant to the task; importantly, this manipulation allowed us to measure the separate contributions of task-relevant and task-irrelevant features to selection (as measured by priming effects). We also predicted that people would vary in the extent to which they process the task-irrelevant feature, and that this variation could be predicted by individual differences in working memory capacity, executive functioning, or personality. Although we found significant priming color independent of orientation in all four experiments, we only observed significant orientation priming in Experiment 1. We also found a negative relationship between visual short-term memory (VSTM) capacity and consecutive priming effects for color in Experiment 1. Additionally, extraversion and neuroticism were significant predictors of overall color priming in Experiment 2. Taken together, our results indicate that limits in VSTM may increase susceptibility to recent visual trends, causing people to attribute importance to visual patterns that are systematic but meaningless. Additionally, we demonstrate that people can select objects in a flexible manner and use whichever feature is easiest to select to guide their attention, regardless of task-relevance.

*For Michael G. Lustig and Gary M. Michal*

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## CHAPTER 1: INTRODUCTION

What determines what people actually see when they look out on the visual world? On the one hand, people are able to use strategies, expectations and goals as a heuristic to guide them toward the most relevant information. For example, when we are stopped at a traffic light, we can attend to the changing colors of the lights without paying attention to the relative locations of the red, yellow and green lights. This type of volitional attention is an example of *feature-based attention*, which allows us to search for a single feature (e.g., the color red) at multiple locations at the same time (e.g. Treue & Trujillo, 1999). However, there are also some aspects of visual perception that we don't have as much control over; for example, when multiple features are contained in a single object, we tend to co-select all features, including task-irrelevant ones (e.g., Duncan, 1984; O'Craven et al., 1999). For instance, while attending to the red light on a traffic light, we may automatically notice that it is located at the top of the traffic light, even though the spatial location of the red light is not important for deciding when to stop or go at an intersection. This phenomenon, referred to as *object-based attention*, illustrates that what we see is also influenced by bottom-up properties of items within the focus of our attention.

Although previous studies have shown that object-based attention is obligatory and has consequences beyond the location of the attended object (e.g., Lustig & Beck, in press; Boehler et al., 2011), there is also recent evidence that object-based attention is not obligatory under certain conditions (e.g., Lustig & Beck, unpublished data; Wegner et al., 2007; Woodman & Vogel, 2008; Levinthal & Lleras, 2008). What factors lead to obligatory object-based selection versus flexible selection of task-relevant and task-irrelevant features? In the following chapters, I will first review the evidence showing that object-based attention is obligatory. In Chapter 2, I will present some unpublished data indicating that object-based attention may not always be obligatory, followed by a discussion of other studies that also failed to find evidence for obligatory object-based attention. Next, in Chapter 3, I will briefly review the literature on intertrial priming studies, in which there is a debate about whether priming occurs for individual features or objects as a whole. In Chapters 4-6, I will present the results of four priming experiments in which varied task conditions and individual differences produce a wide range of priming patterns, ultimately showing that feature selection is much more flexible than previously thought. Finally, I will expand on these results in Chapter 7 and discuss the broader implications of a visual system that is capable of top-down guidance but is also limited in its ability to resist salient bottom-up signals that are spuriously correlated with attended items.

## 1.1. Evidence that object-based attention is obligatory

If you ask a person to make a judgment about a single dimension of an item, it is fairly straightforward (e.g., what is the current color of the traffic light?). What happens when people are asked to make two judgments about an item (e.g., what is the current color and location of the traffic light), and how does this compare to making two judgments about two different items (e.g., the location of the current traffic light and the color of the light below it)? Duncan (1984) was one of the first to show that visual features receive an attentional benefit when they co-occur within the same object. In his experiment, he briefly showed participants a box with a line going through it and asked them to make one or two judgments about a single object (e.g., the box) or about two objects (the box and the line). For example, the box could be big or small and have a gap on the left or right side, and the line could be tilted to the left or right and be a dashed or solid line. Duncan (1984) found that participants were just as accurate at reporting on two dimensions as reporting on a single dimension when the dimensions belonged to the same object (e.g., the box is small and the gap is on the left); however, there was a drop in performance when participants made judgments about two dimensions across the two objects (e.g., the box is small and the line is dashed). He concluded that attending to one dimension of an object leads to co-selection of other dimensions within the same object, or, in other words, that attention is object-based.

In support of this theory, O'Craven et al. (1999) also showed that task-irrelevant features are obligatorily selected along with task-relevant features using fMRI. In this experiment, participants viewed transparent faces superimposed over houses, and either the face or the house moved in a shrinking/growing fashion. Participants were instructed to only attend to the face, the house, or the moving object regardless of category. When participants attended to the face and it happened to be moving, O'Craven et al. not only observed increased activity in the fusiform face area (FFA) but also in the medial temporal (MT+) motion area of the brain relative to activity in the house-related parahippocampal place area (PPA). Similarly, when participants attended to the moving object and it happened to be a face, both MT+ and FFA responses increased relative to activity in the PPA. Thus, attending to a single dimension of an object automatically led to increased responses in brain regions coding task-irrelevant dimensions within the attended object, consistent with Duncan's (1984) behavioral results.

## 1.2. Global effects of object-based attention

Although it has been demonstrated that task-irrelevant dimensions are obligatorily co-selected at the location of the attended object, one unresolved question is what are the consequences of object-based selection beyond the location of the attended object? When a single feature is attended, cells that code that feature increase their response to all locations containing the attended feature, including unattended locations (e.g., Treue & Trujillo, 1999). Does the same mechanism apply to features that are task-irrelevant but co-selected because they are bound to an attended feature within the same object? To investigate this question, we asked participants to monitor the color of one of two superimposed dot fields moving in opposite directions in the right visual field; additionally, a task-irrelevant, colored moving dot field was simultaneously presented in the left visual field (Lustig & Beck, in press). The task-irrelevant stimulus either contained the same or opposite color (task-relevant feature) and the same or opposite direction (task-irrelevant feature) as the attended dot field. Using fMRI, we measured responses to the task-irrelevant stimulus in various regions of visual cortex (V1-V4, V3a and MT+). Based on previous studies on feature-based attention, we expected to observe an increased response in ventral stream areas coding the task-irrelevant stimulus when the stimulus contained the same as opposed to the opposite color as the attended dot field. Additionally, if object-based selection modulates the task-irrelevant feature beyond the location of the attended object, we predicted that dorsal regions coding the task-irrelevant stimulus would also increase activity when the stimulus contained the same as opposed to opposite direction as the attended dot field. As predicted, we found both main effects of color and direction in several regions coding the task-irrelevant stimulus; however, there was not a clear ventral versus dorsal mapping of effects for color versus direction. Instead, areas V1-V4 and V3a showed main effects for both color and direction, whereas MT+ only showed a main effect of direction. Another recent study found that attending to a bi-colored sphere containing one task-relevant and one task-irrelevant color in one visual field leads to an increased ERP response to an unattended sphere in the opposite visual field when it contains the task-irrelevant color versus a different color (Boehler et al., 2011). Interestingly, this global effect of the task-irrelevant color did not emerge until after subjects had spatially selected the target stimulus, whereas global feature-based effects have been shown to occur before spatial selection (Zhang & Luck, 2009). Taken together, these results support the theory of obligatory object-based selection and further suggest that the neural consequences of object-based selection extend globally to task-irrelevant locations.

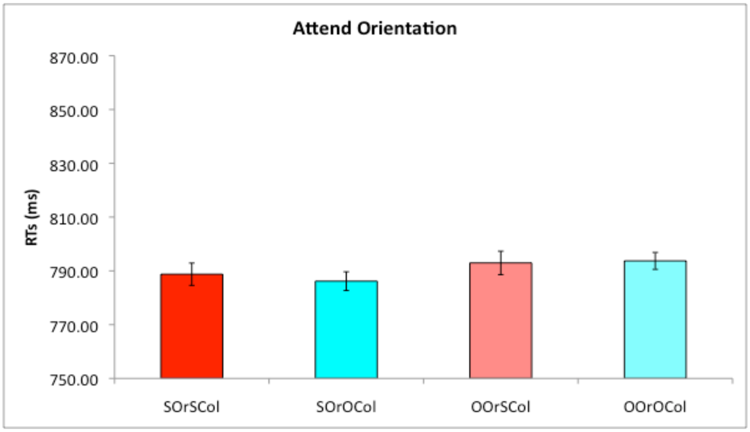
## CHAPTER 2: EVIDENCE THAT OBJECT-BASED ATTENTION IS NOT OBLIGATORY

### 2.1. Behavioral correlates of global object-based attention

Although both Lustig & Beck (in press) and Boehler et al. (2011) demonstrated that the neural mechanism of object-based selection operates in a global fashion, neither of these studies showed behavioral correlates of this mechanism. In order to test whether there are also behavioral consequences to global object-based selection, we asked whether people can detect peripheral items more quickly when they match a centrally attended item on both task-relevant and task-irrelevant dimensions (Lustig & Beck, unpublished data). Participants attended to the orientation (Experiment 1) or the color (Experiment 2) of a group of lines superimposed on another group of lines containing the opposite orientation and color at the center of the screen. In Experiment 1, the task-relevant dimension was orientation, and the color was task-irrelevant (vice versa for Experiment 2). Participants were instructed to detect brief brightening events in the group of lines belonging to the attended dimension. At the same time, participants viewed eight shapes arranged in a circle around the central stimulus, each of which contained a pattern that matched the attended stimulus on both dimensions, one dimension, or neither dimension. For example, if a subject was attending to the leftward tilt group of lines at center that happened to be red, a given peripheral shape could have leftward tilting red lines (same orientation, same color or SOrSCol), leftward tilting blue lines or rightward tilting red lines (same orientation, opposite color or SOrOCol; same color, opposite orientation or SColOOr) or rightward tilting blue line (opposite orientation, opposite color or OOrOCol). At one point during each trial, one of the peripheral shapes also brightened, and subjects were instructed to respond to the shape of the item that brightened (circle or triangle). If there are global behavioral consequences for both task-relevant and task-irrelevant features of an attended object, then people should respond faster to peripheral items that share the task-relevant and task-irrelevant features as the centrally attended item. For instance, in Experiment 1, we predicted that participants would respond faster to peripheral items with the same versus opposite orientation (task-relevant dimension) as the attended stimulus; additionally, we expected that participants would respond faster to peripheral items with the same versus opposite color (task-irrelevant dimension) as the attended stimulus.

The results from both experiments are displayed in Figure 1. As shown in Figure 1A (attend orientation), participants did not show an advantage for detecting peripheral items when it shared the same orientation as the centrally attended item, even though orientation was task-relevant. Not surprisingly then, there was also no advantage for peripheral items that had the same orientation as the central stimulus when orientation was task-irrelevant (Figure 1B, attend color). Finally, subjects were only faster to detect peripheral items that had the same color as the central item when color was task-relevant (Figure 1B).

**A)**




**B)**

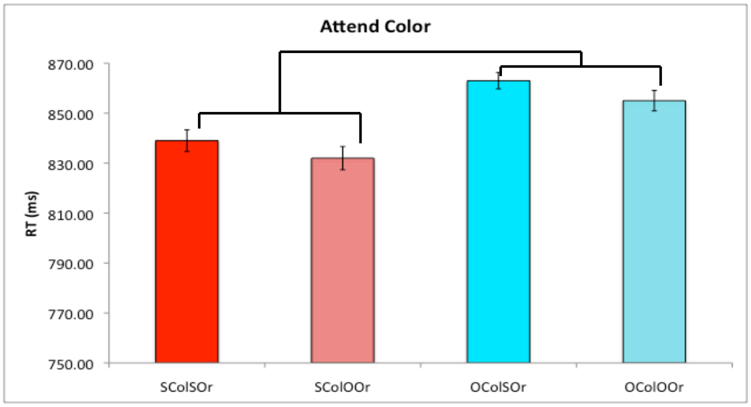



**Figure 1.** RT results from Experiment 1 (A, attend orientation) and Experiment 2 (B, attend color).

2.2. Other evidence that object-based attention is not obligatory

Further analysis revealed that the size of the color effect was associated with overall accuracy on the peripheral shape task; specifically, people with low accuracy showed a significant color effect both when color was task-relevant ($p < 0.01$, Figure 2C) and a marginally significant color effect when color was task-irrelevant ($p = 0.05$, Figure 2A), whereas the high accuracy subjects showed a small but significant color effect when color was task-relevant ($p < 0.05$, Figure 2D) and the opposite pattern (faster for opposite versus same color) when color was task-irrelevant ($p = 0.07$, Figure 2B). In other words, low performers were more sensitive to same-color peripheral items regardless of whether color was task-relevant or not, whereas high performers were only more sensitive to same-color peripheral items when color was task-relevant.

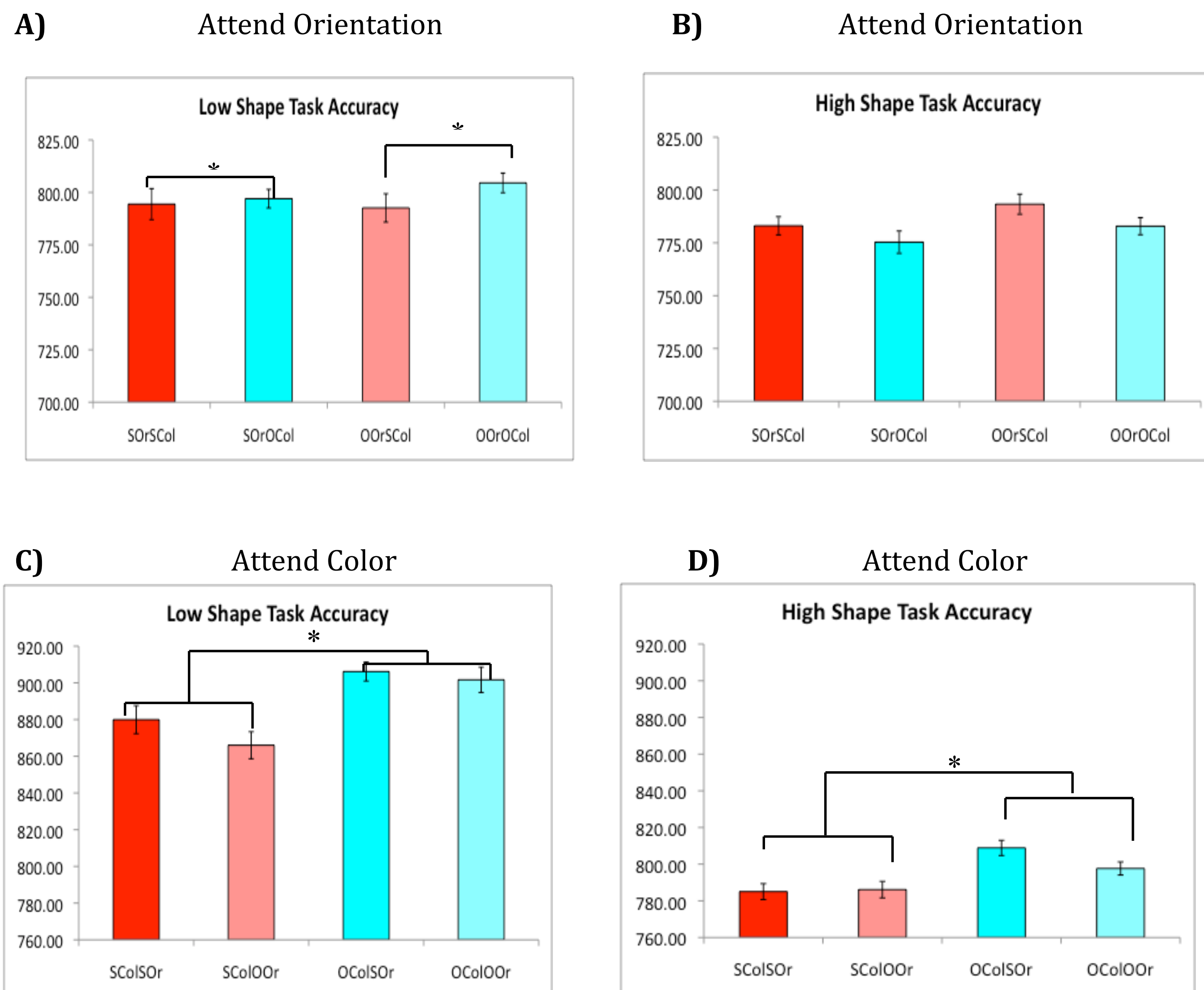



**Figure 2.** RTs by overall shape task accuracy for Experiments 1 and 2. A) Attend orientation, low shape task accuracy group; B) attend orientation, high shape task accuracy group; C) attend color, low shape task accuracy group; D) attend color, high shape task accuracy group.

One possible explanation for this discrepancy is that, whereas low performers attended the task-irrelevant color, the high performers were filtering out the color of the center item when color was task-irrelevant. This would suggest that, contrary to previous theories, co-selection of object dimensions is not automatic. In fact, several recent studies have suggested that object-based selection is not obligatory if there are costs involved with processing task-irrelevant dimensions. For instance, Wegener et al. (2007) used a feature-based cuing paradigm to show that people can prioritize a cued feature (i.e., color) over an uncued feature (i.e., motion speed) even when both features co-occur in an attended object. In their experiment, participants were instructed to detect any changes in an attended object (either color or motion speed), but they received a cue beforehand indicating the feature that was more likely to change. Participants were much faster to detect changes in the attended object when the feature cue was valid versus invalid; additionally, subjects were slower to detect invalidly cued changes compared to when the cue was uninformative as to the feature that would change (i.e., neutral). Thus, when there is a cost to selecting irrelevant features, people are capable of both enhancing relevant features and suppressing irrelevant features, even when the two features co-occur within an attended object.

Woodman & Vogel (2008) demonstrated a similar flexibility in whether subjects encode task-irrelevant features but in a visual short-term memory (VSTM) paradigm. Specifically, they found that when people had to store multiple items in VSTM they are capable of only encoding the relevant features of items (e.g., only the color of colored, oriented bars). Using a change detection task with masks appearing at various delays after a sample display of several colored oriented bars, the authors showed that participants had better performance with shorter SOAs between the sample display and the masks when they had to encode only the bars' colors versus both color and orientation. Thus, when people have to store multiple objects in visual working memory, they use the most efficient strategy (i.e., storing only task-relevant dimensions of objects rather than automatically storing all dimensions of the objects).

We note, however, that in our experiment there were no costs associated with attending to color, and thus the high performers were not obliged to filter out the task-irrelevant dimension. Such a pattern of results suggests that whether a participant co-selects the task-irrelevant dimension is not simply due to task demands but may also be subject to individual differences or other conditions that make a feature-based strategy more favorable.

# CHAPTER 3: FACTORS THAT PROMOTE TASK-IRRELEVANT FEATURE PROCESSING

Taken together, the studies discussed in Chapter 2 indicate that when there is an incentive to prioritize the task-relevant feature of objects, people will not engage in obligatory object-based selection and will instead rely on a feature-based strategy. However, is it *necessary* for there to be a cost associated with task-irrelevant dimensions in order for people to filter them out, or might task-irrelevant feature processing naturally vary with individual differences and task conditions?

## 3.1. Working memory capacity and attentional control

Given that there were no explicit costs associated with the task-irrelevant feature in our behavioral experiment described above, yet some participants still prioritized only the relevant dimension, it is plausible that there are individual differences in the tendency to use object-based versus feature-based strategies. If it is the case that people vary in the extent to which they co-select irrelevant dimensions of attended objects, are there more systematic factors that can predict this variation, such as working memory capacity or executive control?

In support of this possibility, Vogel et al. (2005) demonstrated that individuals vary in the extent to which they encode task-irrelevant items into VSTM. VSTM capacity is traditionally thought of as the limited amount of visual information that can be maintained for a brief period. However, Vogel et al. (2005) showed that VSTM capacity is also highly correlated with the ability to encode only relevant items into VSTM. Participants viewed displays containing two red bars or two red and two blue bars, and they were instructed to remember only the two red bars, all four bars, or only the two red bars when presented along with the two blue bars (e.g., ignoring the blue bars) over a brief delay. The authors measured an ERP response (called the contralateral delay activity or CDA) during the delay period that increases in amplitude with the amount of stored information; thus, the CDA amplitude should be greater when remembering four versus two bars. What happens when participants have to be selective and only remember two red bars while filtering out the two irrelevant blue bars? While some participants were able to filter out the irrelevant items effectively (i.e., the CDA was more similar to delay activity while remembering two bars), others could not filter out the irrelevant items (i.e., the CDA was more similar to delay activity while remembering four bars). Importantly, the ability to filter out irrelevant items was highly correlated with VSTM capacity, suggesting that VSTM capacity is not only a measure of the *number* of items that people can maintain for a brief period, but also of how *flexible* people are in deciding which items/dimensions to maintain online.

There is also evidence that individual differences in executive control (as measured by the OSPAN task, Unsworth et al., 2005) are related to the ability to filter out irrelevant items (Brumback et al., 2005). In the OSPAN task, participants alternate between memorizing lists of letters (ranging from 2-6 letters, presented one at a time) and performing basic arithmetic problems; thus, the task measures multiple executive functions such as working memory, the ability to maintain multiple goals and task-switching. In a sequential discrimination task, Brumback et al. (2005) showed that low OSPAN participants elicited a larger difference in P300 amplitude for target-change trials (e.g., YYX) versus target-repeat trials (e.g., XXX) compared to high OSPAN participants. Because the P300 response occurs after rare or surprising events, this result suggests that low OSPAN participants are more sensitive to the build-up of repeated targets and are thus more surprised when the target changes. Moreover, this implies that high OSPAN participants, due to their larger capacity, have a broader perspective of stimuli changing over time and are better at maintain multiple goals.

Taken together, these data suggest that people vary in their ability to prioritize items and to maintain goals over sequential events. The fact that people can suppress items or features from memory raises the possibility that individuals may also vary in how they attend or select multi-feature items. For instance, do individuals vary in the extent to which they suppress irrelevant *features* of attended items? If people differ in how much they filter out task-irrelevant features within an item, is this variation also associated with VSTM capacity or OSPAN score?

## 3.2 The role of task-irrelevant features in priming

One task that is useful for probing whether task-irrelevant features are flexibly selected is the priming of pop-out (PoP) task, in which participants search for an oddball target across several trials. In this task, the oddball is defined by some specified dimension (e.g., the target has a different color than the distractors, causing it to "pop" out), and the specific feature value of the task-relevant dimension can repeat or change from trial to trial. The classic finding is that priming occurs for the task-relevant dimension: people respond faster to the target when the task-relevant dimension repeats versus when it changes. For example, people respond faster to two red targets in a row versus a red target followed by a green target (e.g., Kristjansson, 2006). There has also been recent interest in whether priming also occurs for task-irrelevant dimensions of targets (e.g., Huang et al., 2004; Kristjansson, 2006; Fecteau, 2007; Levinthal & Lleras, 2008). For instance, if color oddball targets also vary randomly in orientation from trial to trial, are people faster to respond when the orientation repeats versus changes? If priming increases for repetitions of both the task-relevant and task-irrelevant feature versus the task-relevant feature alone, this would support the idea that object-based attention is obligatory, because it would suggest that task-irrelevant dimensions are automatically co-selected along with task-relevant dimensions. Another possibility is that task-irrelevant features are primed independently of the task-relevant feature; this would support the notion that objects are flexibly selected based on individual features.

However, a wide range of task-irrelevant feature priming effects have emerged, so it is unclear whether the evidence is consistent with obligatory object-based attention or a more flexible feature-based strategy. For instance, Kristjansson (2006) conducted a PoP study in which participants searched for an oddball gabor that had a different orientation than the other items (either tilt right or tilt left among all vertical distractors). Each target was either red or green; however, the color of the target was irrelevant to the task. Importantly, this manipulation allowed for an independent analysis of priming for the task-relevant feature (orientation) and the task-irrelevant feature (color). Participants responded faster and faster as the target orientation continued to repeat, consistent with previous priming studies. Responses also quickened as the target color repeated from trial to trial, suggesting that task-irrelevant features can be primed concurrently with task-relevant features. However, the effect of color repetitions was collapsed across trials where only the target color repeated and when both orientation and color repeated; thus, it is unclear whether the task-irrelevant color priming was driven by object-based selection (i.e., only trials when the target repeated both orientation and color), or whether color was primed in an independent, feature-based manner (i.e., similar color priming even when the target orientation changed).

Another study found that repeating the task-irrelevant dimension could facilitate *or* impede response times depending on the fate of the task-relevant dimension (Huang et al., 2004). In this task, participants searched for an oddball target that differed in size from the distractors while its color varied randomly (and was thus task-irrelevant). When the target size repeated, repeating the color led to faster responses; in contrast, when the target size changed, repeating the color *slowed* responses. The authors interpreted this interaction between the task-relevant and task-irrelevant dimensions as evidence that people create episodic memories of each trial and that priming effects emerge at a late stage of processing, after the system has compared the full context of the previous trial to the current trial. In other words, when both features repeat from trial to trial, participants have a conscious sense of "sameness" because everything about the current trial is similar to the previous trial; however, when one feature repeats and one feature changes, there is interference at this decisional stage, leading to slowed responses.

Finally, Levinthal & Lleras (2008) showed that an intertrial priming effect called the distractor preview effect (DPE) occurred for the task-relevant feature, but not for the task-irrelevant feature. In their experiment, participants were instructed to find a color oddball item among other colored items; however, some displays did not contain a target (all items were the same color). Additionally, the colored items had a shape (circle or triangle), which was irrelevant to the task. Typically, when participants fail to find an oddball color singleton (e.g., all red items in the display), it slows their ability to respond to a target on the following trial if the target has the same color as the previous homogenous display (e.g., red target after failing to find a target among red items). Although the authors replicated this effect for the task-relevant color dimension, the task-irrelevant shape of the items on a no-target trial had no influence on participants' ability to find the target on the following trial (e.g., failing to find a color singleton among all circles did not impair the ability to find a circle-shaped target on the following trial). These results suggest that people can flexibly orient to the relevant features of attended objects while completely disregarding task-irrelevant features.

Taken together, the evidence for task-irrelevant feature priming is conflicted and appears to depend on experimental conditions; thus, it is currently unclear how the priming literature contributes to the issue of obligatory object-based attention. However, priming tasks are theoretically ideal for studying the relative contributions of individual features to selection because they allow for task-relevant and task-irrelevant feature processing to be dissociated without instilling a cost to either feature (since feature repetitions can occur randomly). Specifically, we wanted to further investigate whether task-irrelevant features can influence priming in a purely independent manner (i.e., even when the task-relevant feature changes) or if task-irrelevant features are only primed when they co-occur with task-relevant feature repeats. Additionally, given that filtering of task-irrelevant items varies across individuals, could there be individual differences in the tendency to process task-irrelevant features of attended objects, and might this also contribute to variations in task-irrelevant priming effects? In other words, can people flexibly process the task-relevant and task-irrelevant features of objects independently of one another?

# CHAPTER 4: EXPERIMENT 1

## 4.1 Experimental design and methods

To investigate the flexibility of attention to select or filter task-irrelevant features, we developed a priming of popout (PoP) task that was designed to measure priming of task-relevant and task-irrelevant dimensions of target items independently. On each trial, participants viewed a display containing six oriented color gratings arranged in a circle around a fixation point. They were instructed to locate an oddball grating that differed in orientation (0 or 90 degrees) from the other gratings by responding to the visual field of the target (left or right). Since we were interested in the extent to which the task-relevant and task-irrelevant features independently contributed to priming effects (i.e., orientation only and color only repeat trials) as well as the consequence of repeating both features, there were four possible types of target repetitions: only orientation repeated, only color repeated, both orientation and color repeated, or neither orientation nor color repeated. In this experiment, orientation was the task-relevant dimension since targets were defined by their oddball orientation. Importantly, the color of the oddball grating (red or cyan) was irrelevant to the orientation detection task, allowing us to measure the influence of a task-irrelevant dimension. If people vary in the extent to which they use object-based versus feature-based selection strategies, then there should be a wide range of priming for the task-irrelevant color (as indexed by priming from repetitions of color only and both orientation and color).

Additionally, we wanted to know what kinds of factors might be associated with individual variations in object-based selection. In order to correlate individual differences with priming effects, we required a robust sample size; thus, data was collected from 100 subject pool participants. As noted above, we predicted that VSTM capacity might predict the tendency to filter out task-irrelevant features, since one aspect of VSTM capacity is the ability to prioritize relevant over irrelevant information. Thus, we measured VSTM capacity using a change detection task in which six colored squares were briefly presented and reappeared after a short delay with either a single color change or no change to the display. Based on the hit and false alarm rates, we calculated the throughput or $K$ value for each subject using the following formula: $K = N*(H - F)$, where N is the number of items (6), H is the hit rate and F is the false alarm rate. We also hypothesized that processing of task-irrelevant features may be associated with more general executive functioning as indexed by the OSPAN task described above (Unsworth et al., 2005). Finally, we reasoned that variations in object-based selection may vary with personality traits, such as conscientiousness (i.e., more conscientious people may be more likely to follow instructions and rely on task-relevant features more than task-irrelevant ones). Thus, we asked participants to complete a shortened version of the Big Five personality questionnaire (44 questions, John et al., 2008) to investigate whether personality traits might also be associated with the tendency to filter out task-irrelevant features. Participants rated themselves on a scale of 1 (low) to 5 (high) on a variety of questions that measured agreeableness, conscientiousness, extraversion, neuroticism and openness.

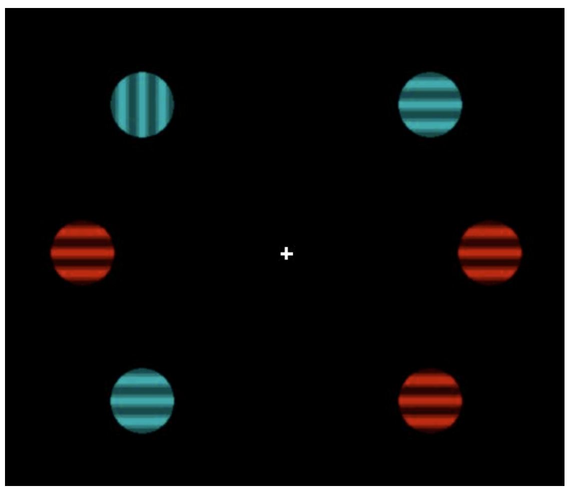


**Figure 3**. Example task display for Experiment 1.

4.2. Results

Figure 4 shows the overall amount of priming for repetitions of orientation only, color only, and both orientation and color. Priming was measured by calculating the average response time (RT) for trials where neither dimension repeated and subtracting average RTs for each repetition condition. There was significant priming for all conditions (orientation, p < 0.001; color, p < 0.02; both, p < 0.001) with greater priming for orientation versus color (p < 0.001) and greater priming when both dimensions repeated versus color (p < 0.001). These results are consistent with previous PoP studies that found priming for both the task-relevant and task-irrelevant dimensions (for review, see Kristjansson & Campana, 2010); however, we also found significant priming for repetitions of color alone, which suggests that task-irrelevant dimensions can be selected in an independent manner.

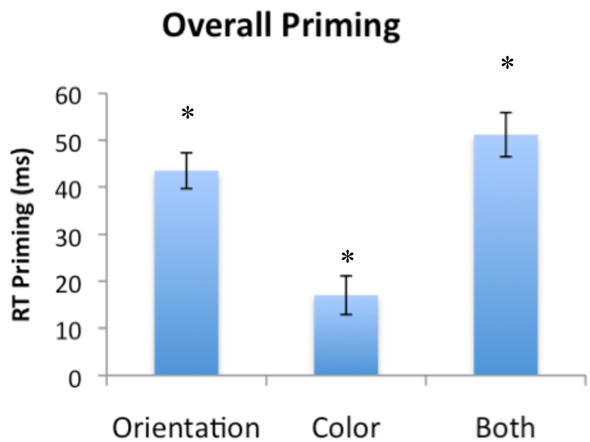



**Figure 4**. Experiment 1 overall priming effects for each repeat condition (orientation only, color only and both features). Priming is calculated by subtracting average RTs to each repeat condition from average RTs to trials where neither feature repeats.

We next asked whether any of our individual differences measures correlated with our three priming effects (orientation, color and both orientation and color) or with a composite priming score (defined as average RTs for no feature repeat trials minus average RTs for the three repeat conditions). The next three figures show correlations between the priming effects for the three repetition conditions and overall priming (i.e. composite priming score) and our individual difference measures of interest (VSTM capacity, OSPAN score, and personality). There were no significant correlations between VSTM and priming for any condition (Figure 5; orientation, $r = 0.05$, $p < 0.6$; color, $r = 0.04$, $p < 0.7$; both, $r = 0.01$, $p < 0.9$; overall, $r = 0.07$, $p < 0.5$). A similar null pattern was observed for correlations between OSPAN score and all priming effects (Figure 6; orientation, $r = -0.1$, $p < 0.3$; color, $r = 0.02$, $p < 0.9$; both, $r = 0.01$, $p < 0.9$; overall, $r = 0.01$, $p < 0.9$). We also did not observe any relationship between priming and personality traits, with the exception of conscientiousness (Extraversion: orientation, r = 0.07, p < 0.5; color, r = 0.01, p < 0.9; both, r = 0.01, p < 0.9; overall, r = 0.01, p < 0.9; Agreeableness: orientation, r = 0.04, p < 0.6; color, r = -0.1, p < 0.3; both, r = -0.06, p < 0.6; overall, r = -0.05, p < 0.6; Neuroticism: orientation, r = 0.008, p < 0.9; color, r = -0.04, p < 0.7; both, r = -0.04, p < 0.7; overall, r = 0.01, p < 0.9; Openness: orientation, r = 0.09, p < 0.4; color, r = 0.08, p < 0.4; both, r = 0.06, p < 0.6; overall, r = 0.07, p < 0.4). For conscientiousness, we observed a range of relationships with priming; there were no significant associations between conscientiousness and orientation or overall priming, but there were moderate (trending toward significant) negative correlations between conscientiousness and priming for color and both dimensions (Figure 7; orientation, $r = 0.1$, $p < 0.3$; color, $r = -0.18$, $p < 0.07$; both, $r = -0.15$, $p < 0.1$; overall, $r = -0.1$, $p < 0.3$), suggesting that the degree to which people filtered the task-irrelevant color (resulting in little color priming) correlated with conscientiousness.

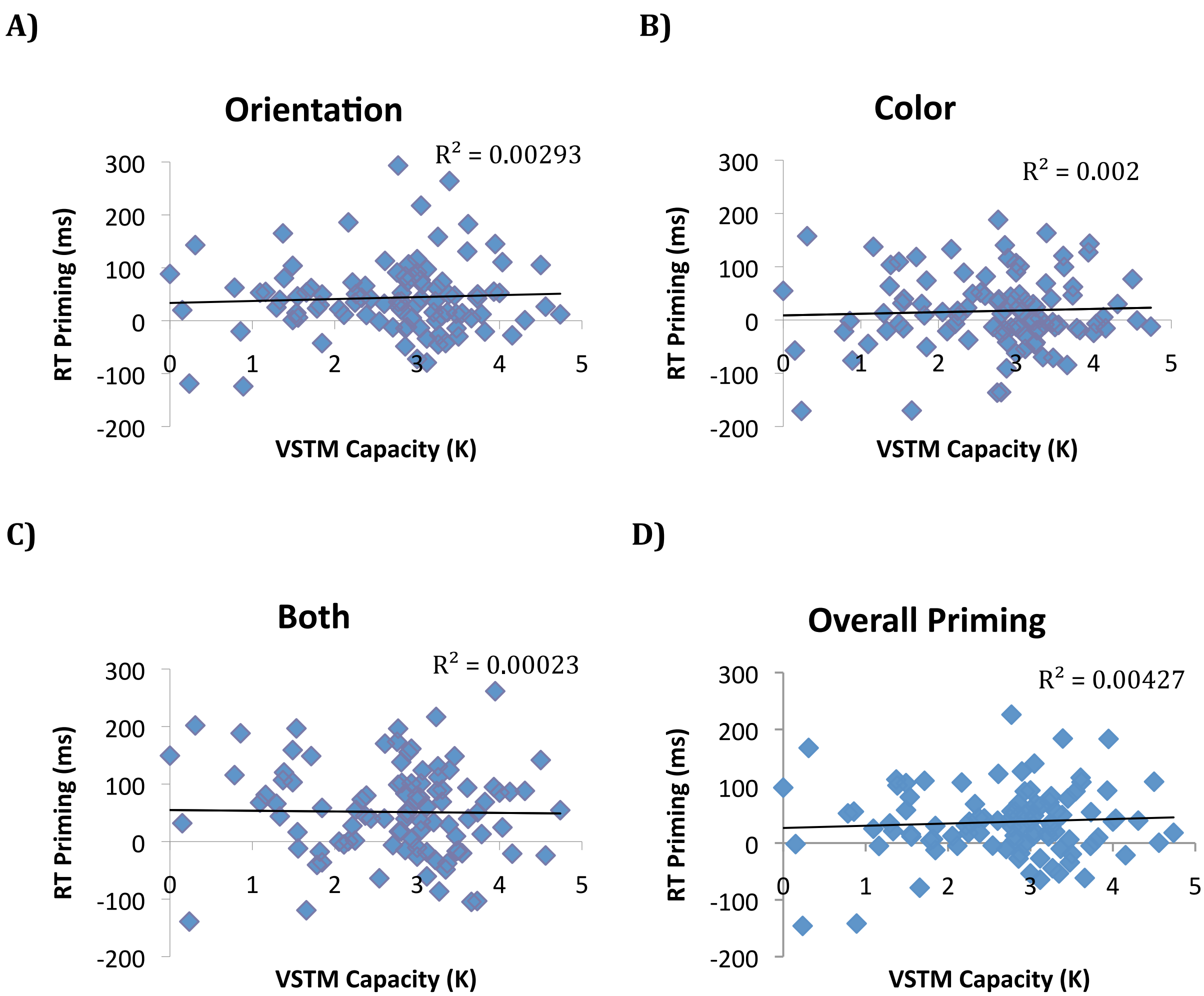



**Figure 5**. Correlations between VSTM capacity and repetition priming for A) orientation, B) color, C) both features, and D) overall priming in Experiment 1.

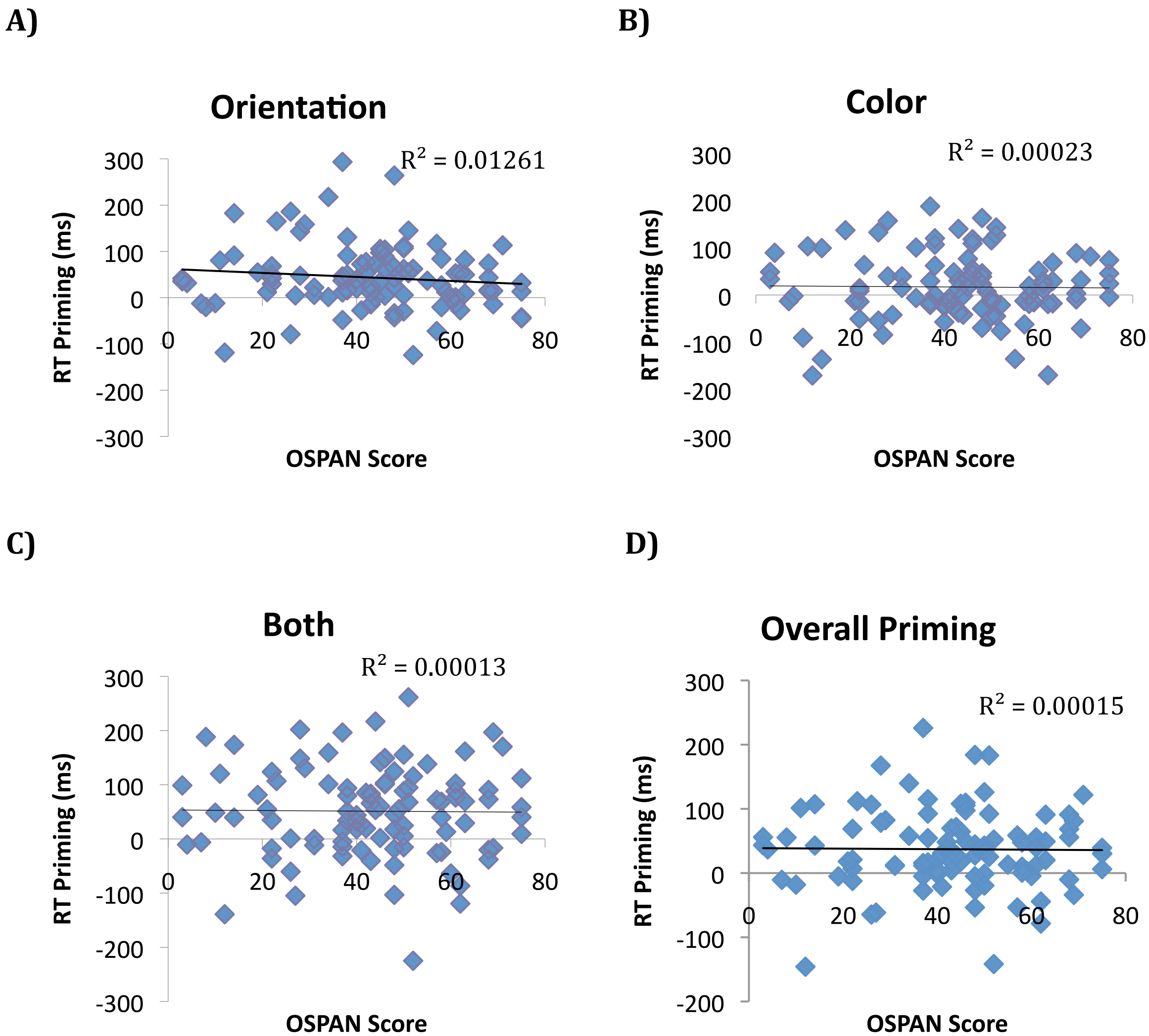



**Figure 6**. Correlations between OSPAN score and repetition priming for A) orientation, B) color, C) both features, and D) overall priming in Experiment 1.

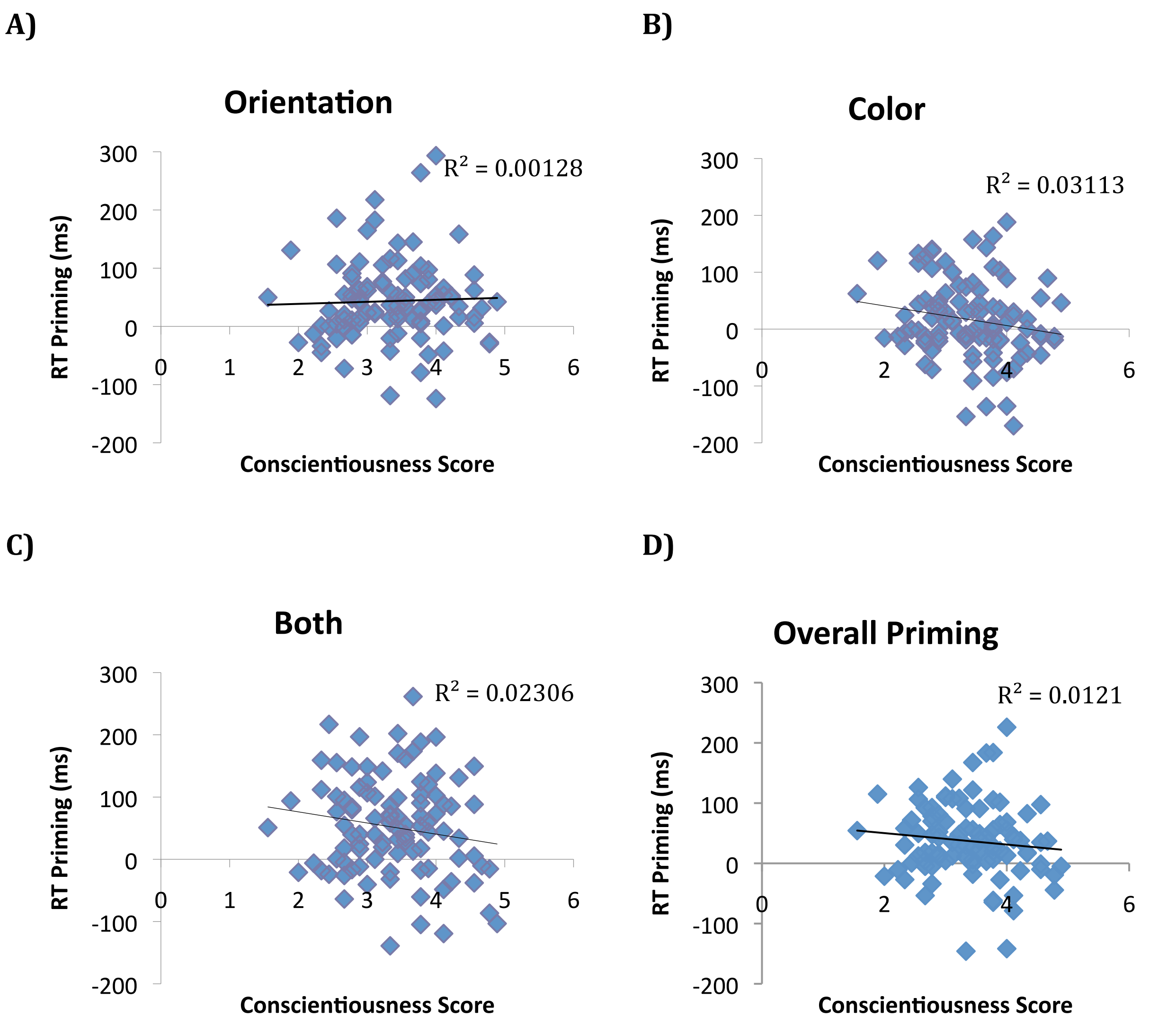



**Figure 7**. Correlations between conscientiousness score and repetition priming for A) orientation, B) color, C) both features, and D) overall priming in Experiment 1.

One benefit of the current study is that we can measure priming effects not only across subjects, but also within subjects. For instance, we can ask whether there is a tradeoff between priming for one dimension over the other. Given the overall pattern of priming effects, is it the case that participants selected task-relevant orientation at the expense of task-irrelevant color? According to the plot in Figure 8, this did not appear to be the case; in fact, there was a significant positive correlation between priming for orientation only and color only repeat trials ($r = 0.57$, $p < 0.0001$). Thus, while orientation led to greater priming than color overall, there was no tradeoff between the two dimensions.

One possible explanation for the positive relationship between priming for orientation and color is that priming effects were driven by slow RTs; that is, the longer a participant took to respond to the target, the more time they had to process both features, which led to similar priming effects for orientation and color. To test this possibility, we compared priming effects for the fastest versus slowest RTs for each subject (defined by the lowest and highest third quantiles of RTs, respectively). As Figure 9 shows, the average priming effects for each repetition condition were similar for the fastest and slowest RTs (main effect of quantile: $F(1,99) = 0.05$, $p < 0.3$); thus, long RTs alone cannot account for the positive correlation between priming for orientation and color.

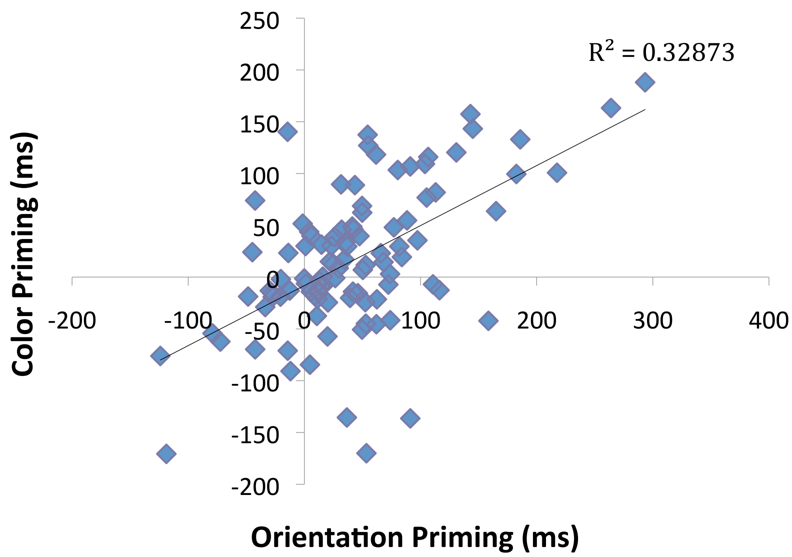



**Figure 8**. Correlation between priming for color only repeats versus orientation only repeats in Experiment 1.

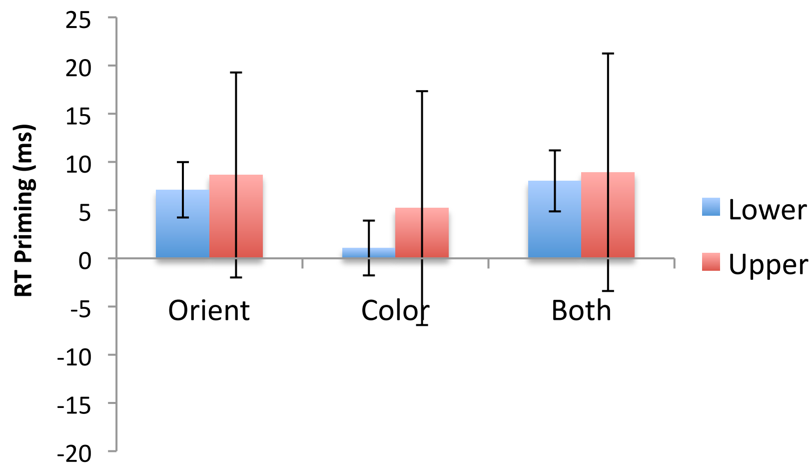



**Figure 9.** RT quantile analysis for Experiment 1. Average priming for each repetition condition is similar for the fastest (lower third) and the slowest (upper third) RTs for each subject.

Next, we measured repetition effects over consecutive trials to compare orientation and color priming after one, two or three or more repeats (Figure 10). In this case, orientation and color priming is collapsed across repeat trials for a single feature and both features (i.e., orientation priming = orientation only + both and color priming= color only + both) since there were not enough consecutive repeat trials for the single feature conditions. As the number of orientation repetitions increased from 1 to 3 or more, RTs were faster (main effect of number of repetitions: $F(2,198) = 4.1$, $p < 0.02$); however, priming for color repetitions was similar across consecutive trials (main effect of number of repetitions: $F(2,198) = 0.12$, $p < 0.9$). This pattern of results is consistent with the notion that participants were more sensitive to repetitions of the task-relevant versus the task-irrelevant feature from trial to trial.

Finally, although there was no relationship between VSTM capacity and priming after a single repetition for any repeat condition, we reasoned that we might be more sensitive to a correlation between VSTM capacity and priming if we considered consecutive priming effects since task-relevant cumulative priming (from 3 repeats) was generally larger than from the first repeat. Moreover, since Brumback et al. (2008) showed that OSPAN predicted the individuals sensitivity to repetitions over time, we reasoned that VSTM or OSPAN might be related to the degree to which priming builds up with repetition. To measure the size of cumulative priming for each participant, we subtracted average priming after 1 repetition from average priming after 3 repetitions for orientation and color repeat trials. Thus, a positive value reflects an increasing sensitivity to the repeating feature, a zero value indicates little sensitivity to feature repetitions, and a negative value suggests increased filtering of the repeating feature. As Figure 11 shows, there was a negative relationship between VSTM capacity and consecutive priming effects both for orientation ($r = -0.1$, $p < 0.3$) and for color ($r = -.22$, $p < 0.03$), but the correlation was only significant for consecutive color repetitions. These results suggest that people with low VSTM capacity are generally more influenced by recent consecutive repetitions than those with high VSTM capacity, consistent with the results of Brumback et al., 2005. Moreover, the relationship between VSTM capacity and cumulative repetitions is stronger for the task-irrelevant color, which may reflect an additional filtering component in high VSTM capacity participants (i.e., they are better able to ignore recent consecutive repetitions overall and especially repetitions in the task-irrelevant dimension).

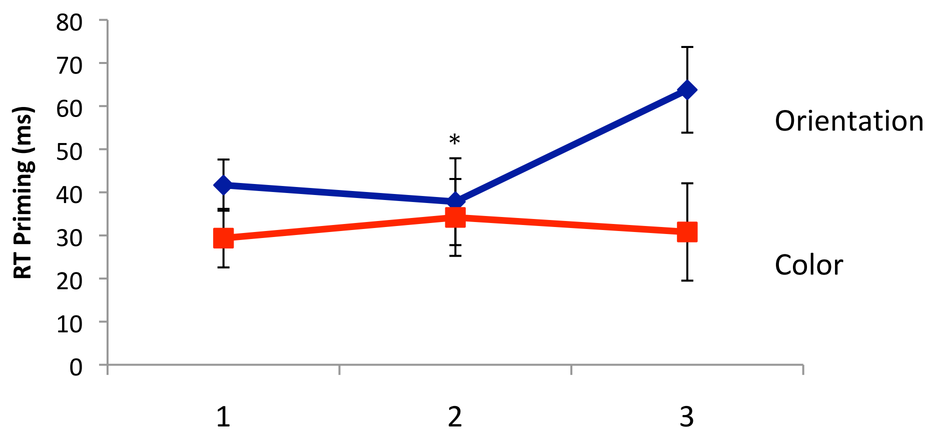



**Figure 10**. Consecutive priming effects for orientation and color in Experiment 1. Priming effects are collapsed across repetitions of a single feature and both features.

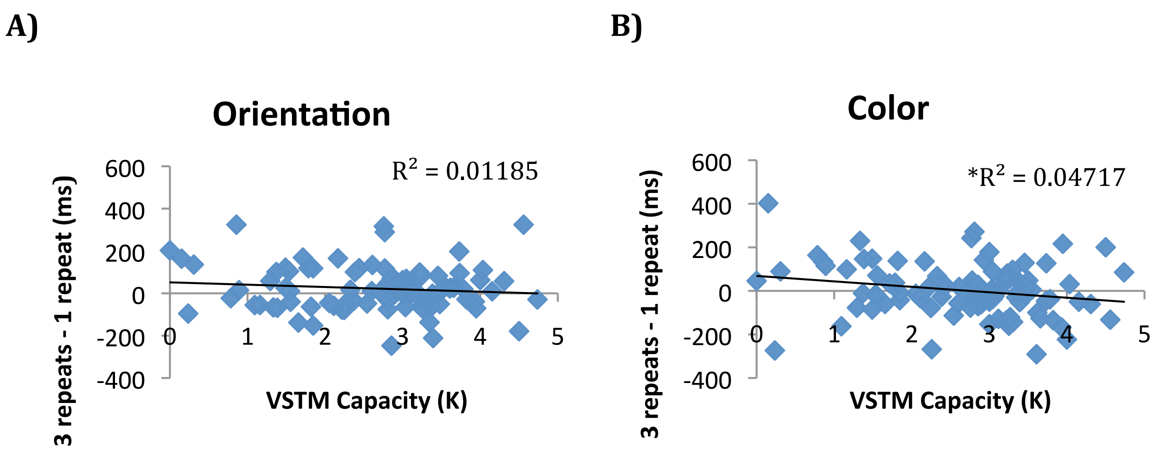



**Figure 11**. Correlation between VSTM capacity and consecutive priming effects for A) orientation and B) color in Experiment 1. Consecutive priming effect = average priming after 3 repeats - average priming after 1 repeat.

Taken together, these results indicate that there is large variation in the amount of average priming for task-relevant and task-irrelevant dimensions. However, it is still unclear what factors contribute to this variation. There are hints of a negative relationship between conscientiousness and priming for the task-irrelevant color. Similarly, VSTM predicted the size of the consecutive priming effect for task-irrelevant color, such that those individuals with the highest VSTM capacity showed the least consecutive priming. However, none of our measured factors (VSTM capacity, OSPAN score or conscientiousness) appear to be a strong predictor of task-irrelevant feature priming. Thus, it does not appear that individual differences in filtering can predict whether a participant is likely to select targets in an obligatory, object-based way versus a flexible, feature-based way, at least with the current task conditions. One possible explanation for these weak associations is that the current PoP task may have relied more on bottom-up versus top-down processes. For instance, because the target was always a pop-out, it was fairly easy to locate and may not require much attentional control on the part of the participant; thus, participants may not have processed the target in a focused, object-based manner in the first place. Additionally, although color was initially chosen as the task-irrelevant dimension because it is relatively more salient than orientation, the color may have been too easy to ignore in the current PoP task due to the large number of items; thus there may not have been enough of an incentive to filter out the irrelevant color.

For these reasons, we conducted a second experiment to test whether the individual differences factors from Experiment 1 would show stronger associations with performance on a PoP task that relies more on top-down processing. By increasing the top-down demand of the search task, we hoped to push participants to rely more on the task-relevant versus the task-irrelevant feature, thus increasing the potential for variation in filtering ability.

# CHAPTER 5: EXPERIMENT 2

## 5.1 Experimental design and methods

In Experiment 2, participants performed a PoP task similar to the task in Experiment 1, but with several changes (example experimental display shown in Figure 12). To increase the top-down demands of search task, the oddball target orientation was either oriented 45° to the left or right instead of horizontally or vertically, which served to make the target less salient (i.e. the target differed by 45° from the distractors, instead of by 90° as in Experiment 1). In addition, the distractor orientations were either all vertical or all horizontal. We varied the orientation of the distractors randomly from trial to trial in order to assess whether individual differences might also predict priming for distractor repetitions, since distractor repetitions contribute to overall priming effects independently of target repetitions (e.g., Lamy et al., 2008). To maximize priming effects further, we reduced the number of items from 6 to 4, since fewer items produce larger priming effects (e.g., Meeter & Olivers, 2006) and to decrease the likelihood of the target color popping out in a single visual field (i.e., a red target appears between two blue targets). Finally, to decrease the predictability of target location, possible locations were jittered such that there were two possible diamond configurations of target/distractor mappings (i.e., the target and distractors could appear in locations 1, 3, 5, or 7 on one trial or in locations 2, 4, 6, or 8 on another trial). The task was again to locate the visual field of the oddball target, defined by its unique orientation. Target color was once again task-irrelevant and varied between red and cyan randomly from trial to trial. Similar to Experiment 1, we ran 100 subject pool participants to fully examine relationships between individual differences and priming.

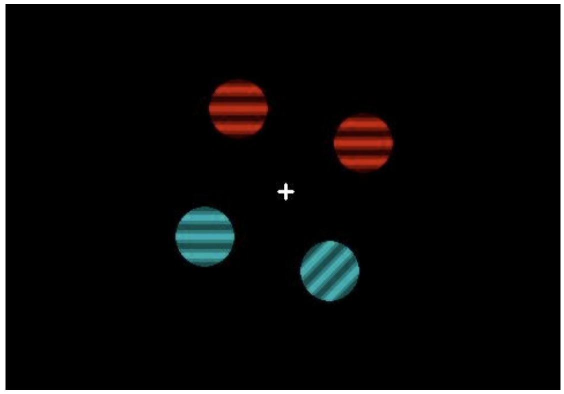


**Figure 12**. Example task display for Experiment 2.

5.2. Results

Overall priming effects are shown in Figure 13. One immediately apparent result is that there was no significant effect of priming for orientation alone ($p < 0.2$), despite the fact that orientation was the task-relevant feature. In contrast, the priming effects for color alone and both features were well above zero (color, $p < 0.001$; both, $p < 0.001$). Additionally, priming for color and for the "both" condition was significantly greater than orientation priming ($p < 0.0001$ for both comparisons), and priming for the both condition was significantly greater than color priming ($p < 0.04$). Although unexpected, this pattern of results reinforces the finding above that the task-irrelevant feature can be primed independently of the task-irrelevant feature.

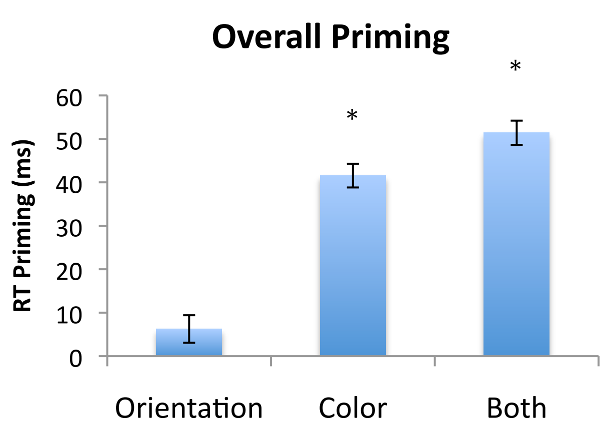



**Figure 13**. Overall priming effects for Experiment 2.

We again plotted the relationship between our factors of interest and priming effects for each repetition condition. Similar to Experiment 1, there were no significant correlations between VSTM capacity and priming for any repetition type, though there was a trend for a negative relationship between VSTM capacity and orientation priming (Figure 14; orientation, $r$ = -0.18, $p < 0.07$; color, $r$ = 0.013, $p < 0.9$; both, $r$ = -0.055, $p < 0.6$; overall, $r$ = -0.097, $p < 0.3$)

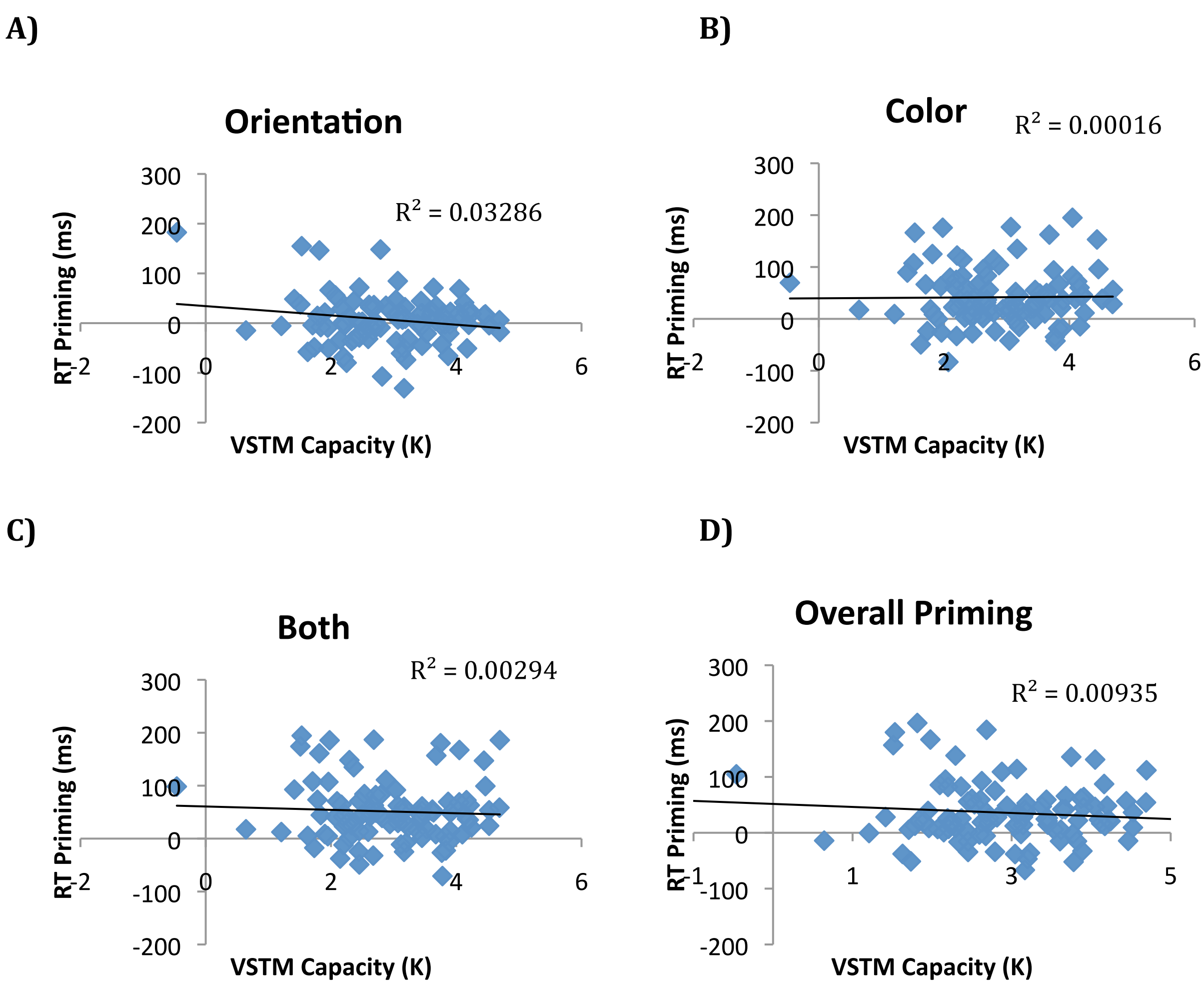



**Figure 14**. Correlation between VSTM capacity and repetition priming for A) orientation, B) color, C) both features, and D) overall priming for Experiment 2.

There were also no correlations between OSPAN score and priming effects for each repetition type (plotted in Figure 15: orientation, $r = -0.03$, $p < 0.8$; color, $r = -0.047$, $p < 0.6$; $r = 0.04$, $p < 0.7$; overall, $r = -0.062$, p < 0.5).

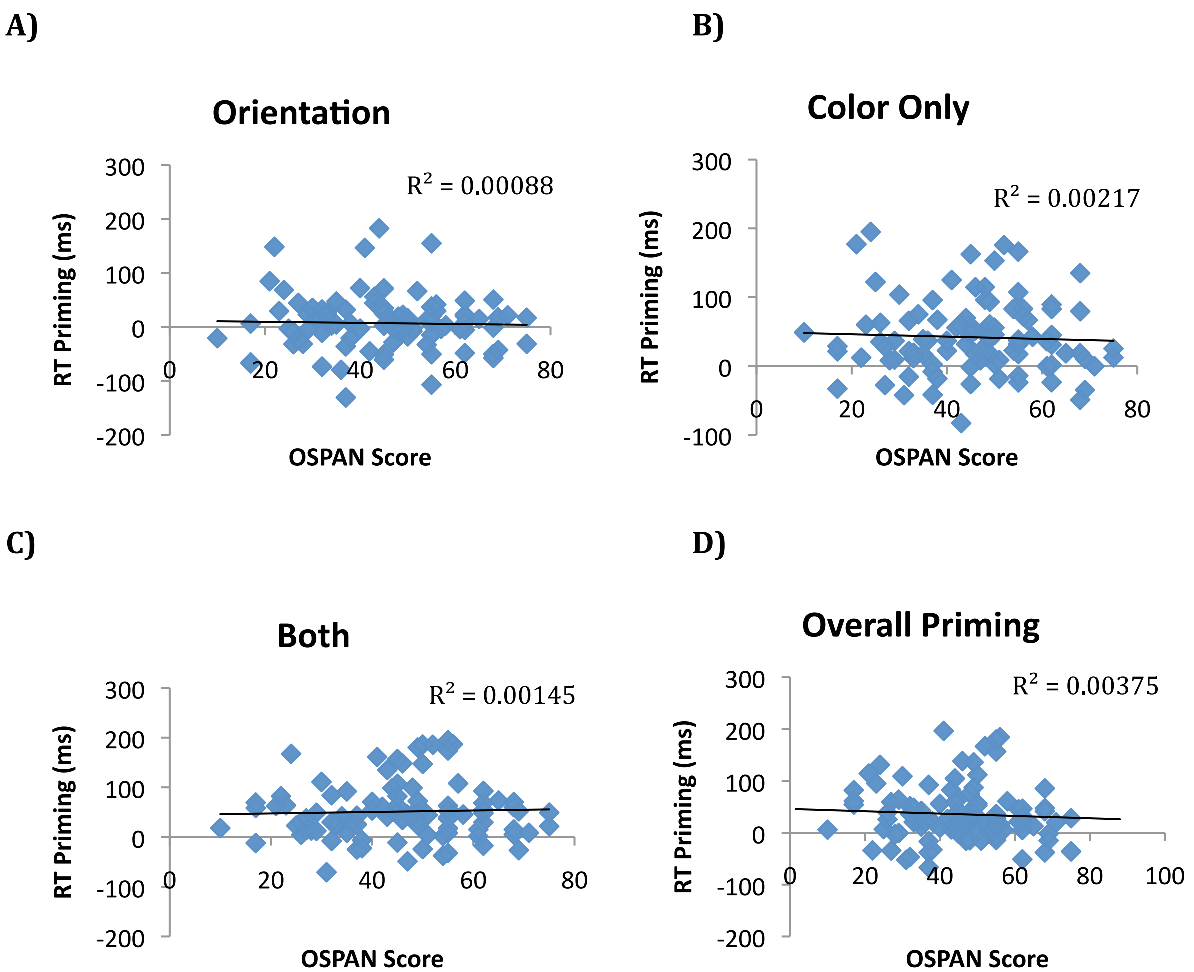



**Figure 15.** Correlation between OSPAN score and repetition priming for A) orientation, B) color, C) both features, and D) overall priming for Experiment 2.

Finally, relationships between conscientiousness and priming effects are plotted in Figure 16. In contrast to Experiment 1, in which orientation priming was unrelated to conscientiousness and color and both feature priming was negatively correlated with conscientiousness, conscientiousness was generally positively associated with all priming effects in the second experiment, but not significantly (orientation, $r = 0.15$, $p < 0.1$; color, $r = 0.13$, $p < 0.2$; both, $r = 0.14$, $p < 0.16$; overall, $r = 0.045$, $p < 0.7$). Interestingly, there was also a positive relationship between extraversion and priming, but only for color repetitions (Figure 17; orientation: $r = 0.08$, $p < 0.4$; color, $r = 0.24$, $p < 0.02$; both, $r = 0.26$, $p < 0.01$; overall, $r = 0.14$, $p < 0.2$). Conversely, there was a negative relationship between neuroticism and color priming (Figure 18; orientation, $r = 0.04$, $p < 0.7$; color, $r = -0.24$, $p < 0.02$; both, $r = -0.18$, $p < 0.07$; overall, $r = -0.08$, $p < 0.4$). No other personality variables were systematically associated with priming (Agreeableness: orientation, $r = 0.003$, $p < 0.98$; color, $r = 0.03$, $p < 0.8$; both, $r = 0.004$, $p < 0.97$; overall, $r = -0.02$, $p < 0.8$. Openness: orientation, $r = 0.09$, $p < 0.4$; color, $r = -0.05$, $p < 0.6$; both, $r = 0.004$, $p < 0.97$; overall, $r = -0.11$, $p < 0.3$).

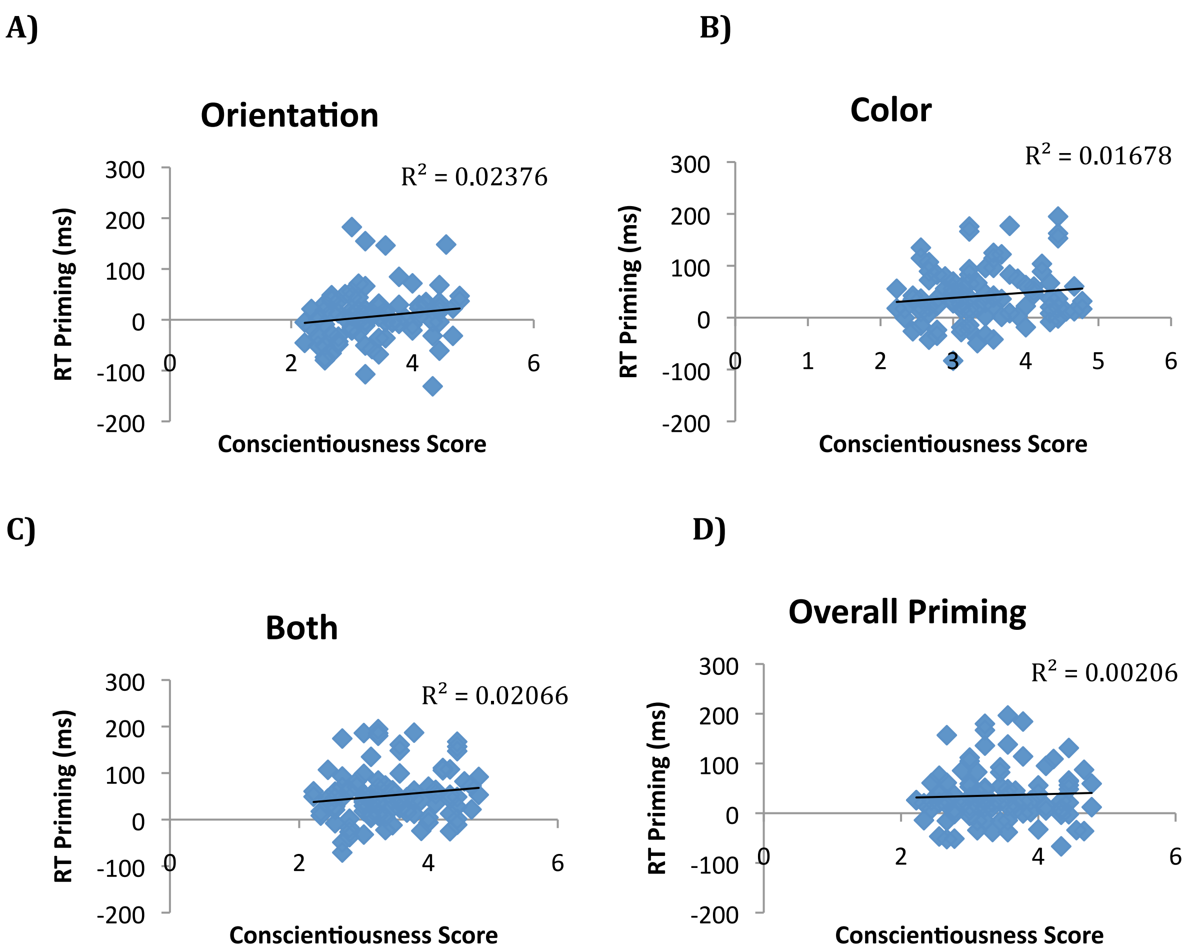



**Figure 16.** Correlation between conscientiousness score and repetition priming for A) orientation, B) color, C) both features, and D) overall priming for Experiment 2.

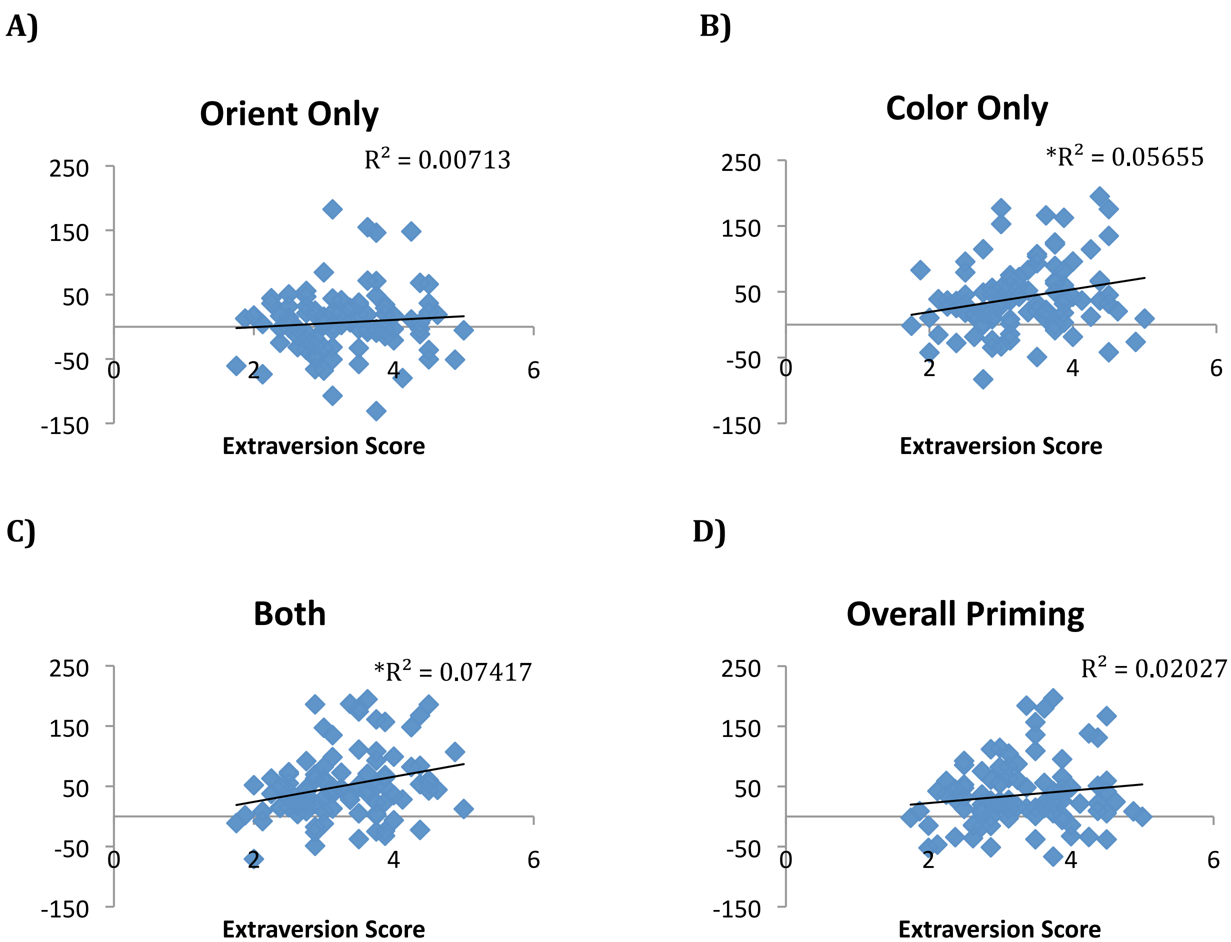
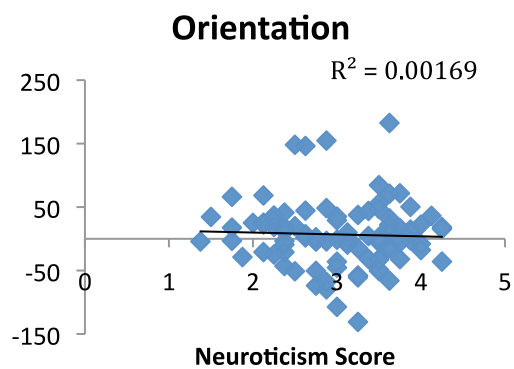
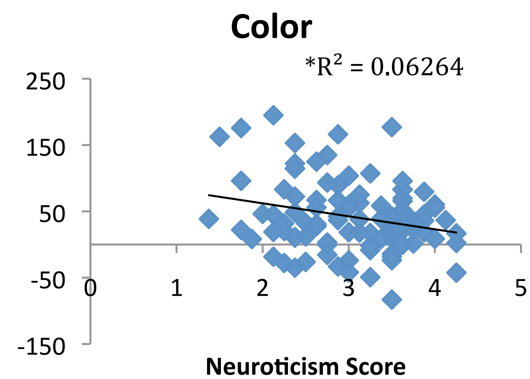



**Figure 17.** Correlation between extraversion score and repetition priming for A) orientation, B) color, C) both features, and D) overall priming for Experiment 2.

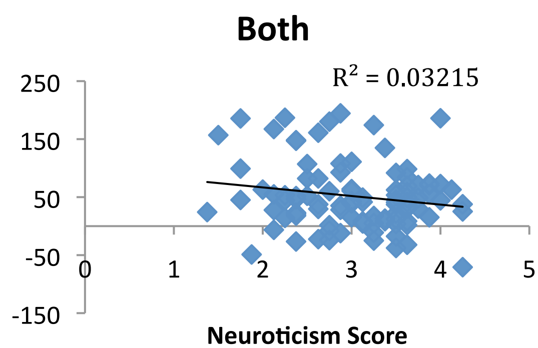
**A)**




**B)**




**C)**




**D)**

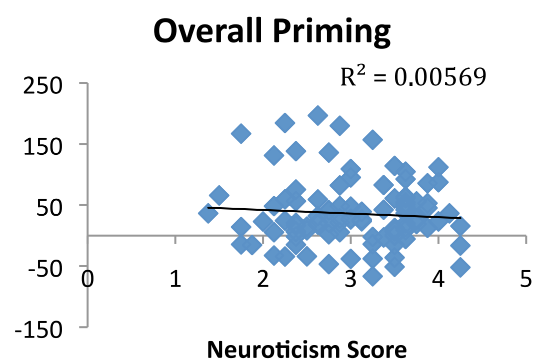



**Figure 18.** Correlation between neuroticism score and repetition priming for A) orientation, B) color, C) both features, and D) overall priming for Experiment 2.

Given the relatively independent contributions of priming from the task-relevant and task-irrelevant feature, we again assessed whether there was a tradeoff between priming for orientation and color. As shown in Figure 19, orientation priming was significantly associated with color priming in a positive way ($r = 0.48$, $p < 0.0001$); thus, participants did not rely on color repetitions at the expense of orientation repetitions. As in Experiment 1, the correlation between orientation and color priming was not driven by only the slowest RTs within subjects as RT did not predict the amount of priming for any condition (Figure 20; main effect of quantile, $F(1,99) = 0.9$, $p < 0.4$).

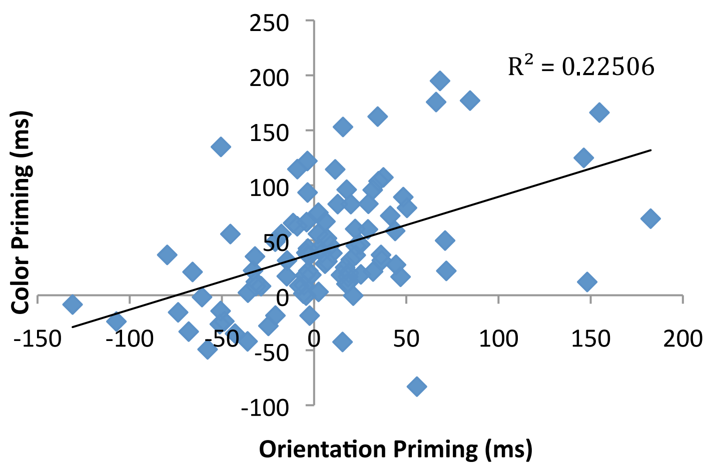



**Figure 19.** Correlation between priming for color repeats versus orientation repeats in Experiment 2.

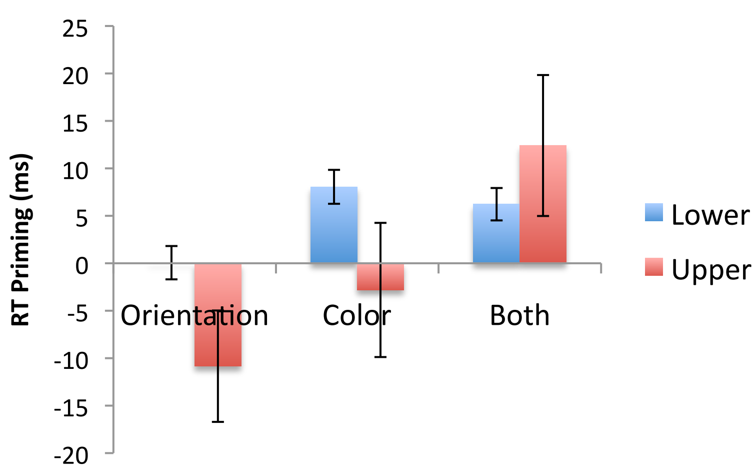



**Figure 20**. RT quantile analysis for Experiment 2. Priming is similar for the fastest (lower third) and the slowest (upper third) RTs.

Recall that in addition to finding increased priming for orientation versus color overall in Experiment 1, we also only observed consecutive priming effects over multiple trials for orientation. However, since there was greater priming for color versus orientation in Experiment 2, this pattern might be expected to be reversed, with consecutive priming effects only occurring for color, but not for orientation. This is in fact what we found (Figure 21); priming increased with consecutive color repetitions (main effect of number of repetitions, $F(2,198) = 5.4$, $p < 0.005$) but not with consecutive orientation repetitions (main effect of number of repetitions, $F(2,198) = 0.9$, $p < 0.4$).

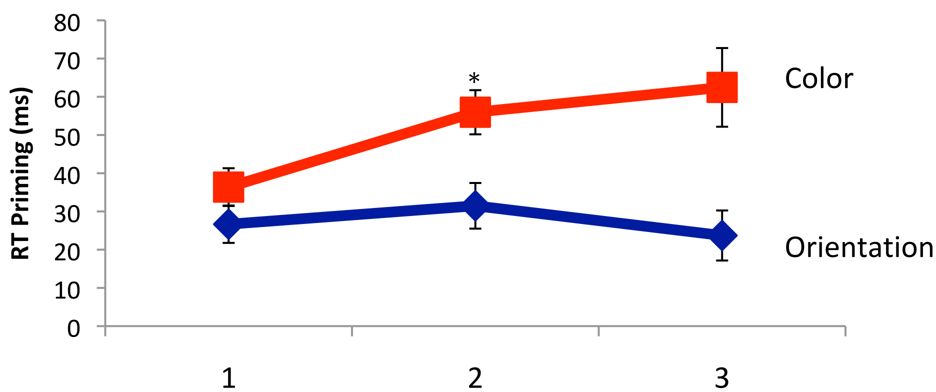



**Figure 21**. Consecutive priming effects for orientation and color in Experiment 2.

We again investigated whether VSTM capacity might be predictive of consecutive priming effects on an individual basis using the same calculation for cumulative repetition priming described in Experiment 1. Although the overall patterns of consecutive priming for orientation and color were essentially reversed from Experiment 1 to Experiment 2, the relationship between VSTM capacity and consecutive priming for color was similarly negative in Experiment 2, but this correlation was not significant (Figure 20B; $r = -0.14$, $p < 0.16$). Perhaps not surprisingly, since there was little priming for orientation overall in Experiment 2, there was little relationship between VSTM capacity and consecutive orientation priming (Figure 22A; $r = -0.086$, $p < 0.4$).

A) B)

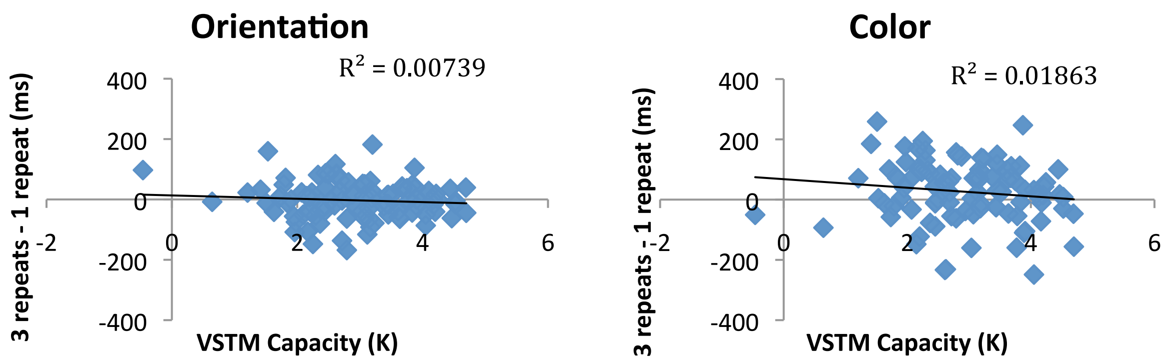



**Figure 22**. Correlation between VSTM capacity and consecutive priming effects for A) orientation and B) color in Experiment 2. Consecutive priming effect = average priming after 3 repeats - average priming after 1 repeat.

Finally, because the distractor orientation was uncorrelated with the target orientation in Experiment 2, we were able to measure the effect of distractor priming independently of target priming. However, there was no effect of repeating the distractor orientation (horizontal or vertical) on overall RTs (Figure 23A; $p < 0.2$). Given that sensitivity to distractor identity might also rely on filtering ability, we also tested whether VSTM capacity was predictive of distractor priming, but this was not the case (Figure 23B; $r = 0.033$, $p < 0.7$). Thus, there was minimal contribution of distractor repetitions to priming in this experiment.

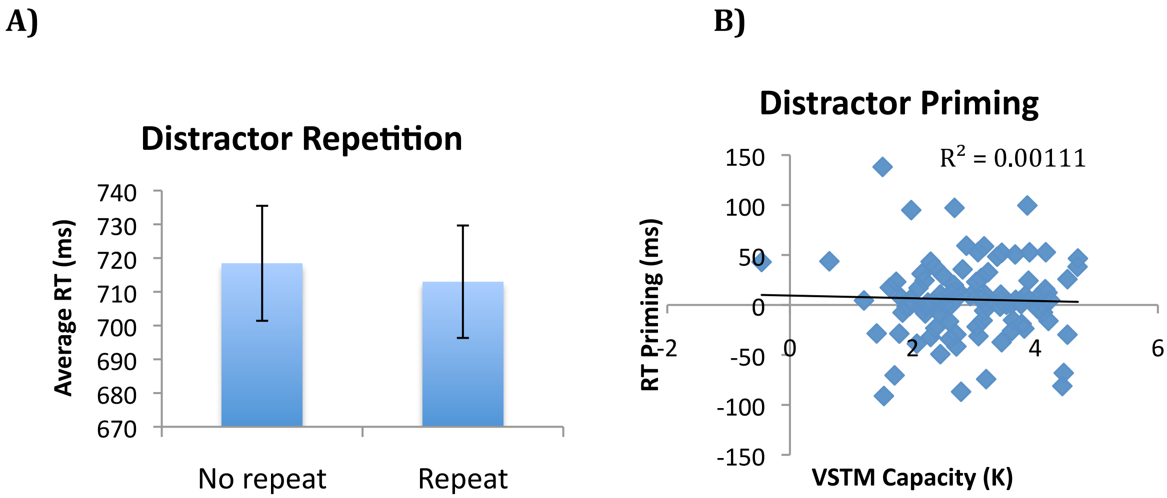



**Figure 23.** Effects of distractor orientation repetition in Experiment 2. A) Average RTs to distractor switch versus distractor repeat trials. B) Correlation between VSTM capacity and distractor priming.

Although our initial goal for Experiment 2 was to increase priming for the task-relevant dimension and decrease the influence of the task-irrelevant dimension, we actually observed the opposite pattern; both overall priming and consecutive priming effects were much stronger for color repetitions, not orientation repetitions. What factors can account for the reversed priming effects observed in Experiment 2? One possibility is that Experiment 1 allowed participants to simultaneously rely on both target and distractor repetitions of orientation, since the target orientation was perfectly correlated with distractor orientation (i.e., horizontal target always appeared with vertical distractors or vice versa). Although we did not observe a significant effect of distractor repetition in Experiment 2, it is still possible that the lack of a relationship between target and distractor influenced subjects approach to the task. In other words, although we were interested in the independent effects of target and distractor repetitions in Experiment 2, we might have unwittingly changed a critical factor by removing the correlation between target and distractor orientation. In Experiment 3a, we tested this possibility by running a follow-up experiment using the same PoP task as in Experiment 2, except that the target and distractor orientations were perfectly anticorrelated.

In addition to observing a reduced orientation priming effect, we also found an increased effect of color priming from Experiment 1 to Experiment 2. Although we decreased the number of distractors in Experiment 2 in order to increase priming, we may have inadvertently increased color signal by reducing the number of items. For example, with only four items, there was a greater chance for two items of the same color to appear adjacent to one another, which could have actually boosted the task-irrelevant color of the target. Moreover, with only two colors the displays naturally group into two two-item pairs. If subjects attended to one of those groups, and it happened to contain the target, then the target was easily detected. If subjects happened to attend to the group that did not contain the target, this was readily apparent (by the fact that the items were identical) and he or she could quickly switch to the other group. In other words, our displays may have provided subjects with a convenient method for finding the target which, although not as efficient (theoretically) as searching for the oddball orientation, may have proven easier than ignoring the very salient colors. In order to test this hypothesis, we conducted a second follow-up experiment (Experiment 3b) in which the task-irrelevant color varied among four possible colors; thus, the target and each distractor had a unique color. These displays would no longer group on the basis of color, and thus subjects may be able to better use orientation to find their target. On the other hand, if color is just more salient than our orientation manipulation then, subjects may continue to orient to the repeated color.

# CHAPTER 6: EXPERIMENTS 3A AND 3B

## 6.1. Experiment 3a design and methods

The PoP task was identical to the task described in Experiment 2, with the exception that the target orientation was now perfectly correlated with the orientation of the distractors. Specifically, tilt-right targets always appeared with horizontal distractors, while tilt-left targets always appeared in the context of vertical distractors. 13 subjects participated in the experiment.

## 6.2. Experiment 3b design and methods

The PoP task was identical to the task described in Experiment 2 except that target and distractor colors varied randomly among four possible colors (red, green, cyan and yellow). Thus, the target and distractor colors were always unique on each trial; additionally, the chance of a specific target color repeating was reduced from 50% (two possible colors) in Experiment 2 to 25% (four possible colors). The same 13 subjects who participated in Experiment 3a also participated in Experiment 3b, with the order of experiments counterbalanced across subjects.

6.2. Experiment 3a and 3b Results

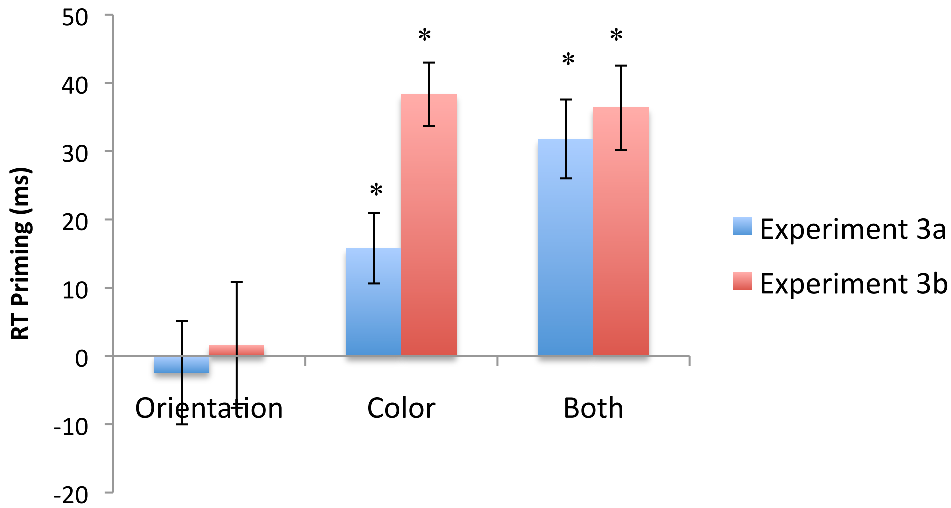



**Figure 24**. Overall priming effects for Experiments 3a and 3b.

Overall priming effects for Experiments 3a and 3b are shown in Figure 24. Once again, orientation repetitions failed to produce significant priming in both experiments (Experiment 3a, $p < 0.6$; Experiment 3b, $p < 0.8$); however, repetitions of color and both features led to significant priming for both experiments (Experiment 3a: color, $p < 0.04$; both, $p < 0.002$; Experiment 3b: color, $p < 0.002$; both, $p < 0.003$). Interestingly, there was similar priming among the repetition conditions across the two experiments (orientation, $p < 0.7$; both, $p < 0.6$), with the exception of color; there was significantly greater priming for color repetitions in Experiment 3b versus 3a ($p < 0.002$). This was especially notable given that the aim of Experiment 3b was to reduce the influence of color on priming by decreasing the salience of target color.

Similar to Experiments 1 and 2, we further probed these overall priming effects by measuring consecutive priming for orientation and color (Figure 25); again, consecutive priming was calculated by collapsing repetitions of the feature alone and when both features repeated. Surprisingly, although there was little overall priming for repetitions of orientation alone in Experiment 3a, there was a significant effect of number of consecutive orientation repetitions, with orientation priming increasing from one to three or more repeats (Figure 25A; $F(2,24) = 3.8$, $p < 0.04$). This pattern was most likely driven by trials where both orientation and color repeated; however, it is also possible that participants were better able to pick up on orientation repetitions because they were more likely to notice distractor orientations after consecutive repetitions. In contrast, there was no effect of number of color repetitions for Experiment 3a ($F(2,24) = 1.4$, $p < 0.3$). There were also no effects of number of repetitions for either color or orientation in Experiment 3b, despite the large priming effect of color overall (Figure 25B; orientation, $F(2,24) = 1.7$, $p < 0.2$; color, $F(2,24) = 2.2$, $p < 0.1$). However, it is possible that the lack of an effect of consecutive color repetitions is due to the fact that there were fewer opportunities for color to repeat in Experiment 3b (25% versus 50% chance of color repetition).

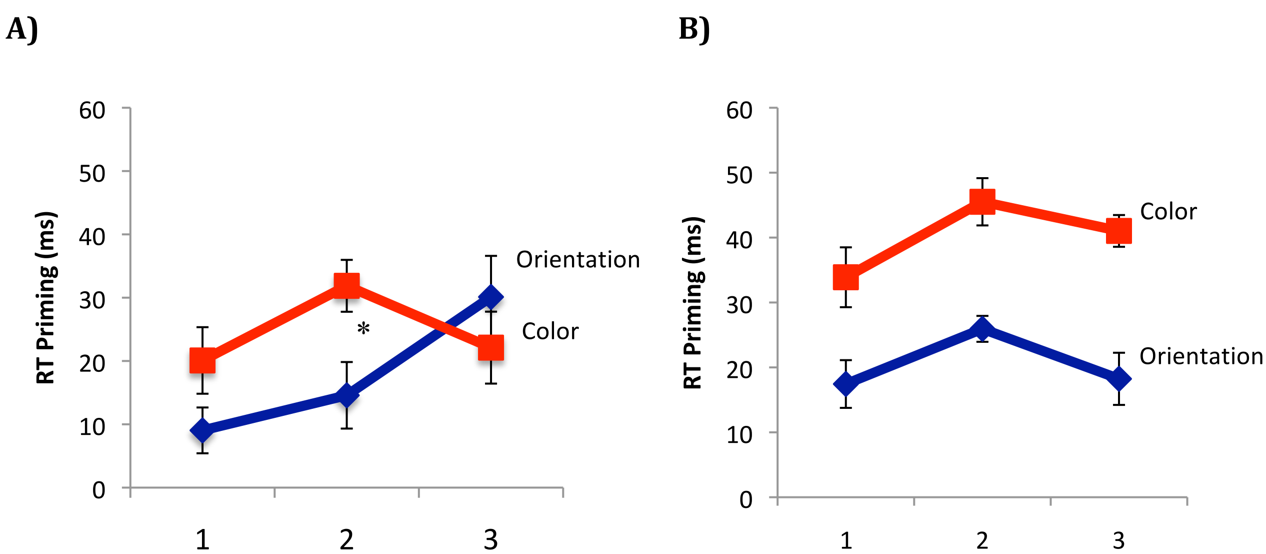



**Figure 25**. Consecutive priming effects for orientation and color in A) Experiment 3a and B) Experiment 3b.

# CHAPTER 7: CONCLUSIONS AND DISCUSSION

## 7.1. Overview

Although there is much evidence that attention is object-based (i.e., all features of attended objects tend to be co-selected, e.g., O'Craven et al.), growing evidence suggests that object-based attention is not always obligatory. The goal of the experiments above was to test the hypothesis that people can attend to multidimensional objects in a flexible manner. Specifically, we investigated whether people can prioritize individual features of objects even when there is no explicit incentive to do so. To test this idea, we used the PoP task with multidimensional targets (containing orientation and color) to dissociate processing of task-relevant and task-irrelevant features. Because target features repeat randomly from trial to trial in this task, there is no explicit reason to filter out the task-irrelevant feature; however, we expected that people might vary in the extent to which they rely on repetitions of the task-irrelevant feature. Originally, we predicted that the tendency to process the task-irrelevant feature might vary with individual differences in working memory capacity, such as VSTM capacity or OSPAN, or possibly even differences in personality traits, such as conscientiousness. In Experiment 1, although there was a wide range of priming effects for both the task-relevant and task-irrelevant feature, none of the individual difference factors were strong predictors of priming for the task-irrelevant dimension, suggesting that participants were not actively inhibiting task-irrelevant features in this task. In support of this, there were no tradeoffs between priming for the task-relevant and task-irrelevant dimension. We reasoned that the PoP task from Experiment 1 may have been too easy and thus might explain why associations with individual differences in top-down control were weak; thus, we designed a more difficult search task to increase the top-down demand in Experiment 2. However, for reasons that are still not fully understood, this new PoP task produced some unexpected results: priming for the task-relevant feature was abolished, while priming for the task-irrelevant feature increased substantially. Additionally, although the new task failed to produce any significant relationships between individual differences in working memory capacity and priming, we did observe a positive association between extraversion and color priming and a negative relationship between neuroticism and color priming. We speculated that the decreased priming effect for the task-relevant feature in Experiment 2 could have been a result of decorrelating the target and distractor orientations and/or a result of increasing the salience of target color. We tested these hypotheses in Experiments 3a and 3b, respectively; however, we failed to improve task-relevant priming in Experiment 3a, and task-irrelevant priming actually increased in Experiment 3b relative to Experiment 3a. Finally, consecutive priming effects generally only increased for the dimension for which there was greater overall priming (i.e., orientation in Experiment 1 and color in Experiment 2), with the exception of Experiment 3a, for which there was little overall priming for orientation, but a significant consecutive orientation priming effect. Although individual differences in VSTM capacity were not predictive of task-irrelevant feature priming overall, we did find a negative relationship between VSTM capacity the amount of cumulative priming effects for task-irrelevant color in Experiment 1. This result suggests that people with low VSTM were more influenced by build-up of the task-irrelevant dimension over consecutive trials.

## 7.2. General conclusions

What can we conclude from these complicated patterns of results? One thing is clear: despite the fact that color was always task-irrelevant, participants relied on color repetitions whenever they could. Although color was initially chosen to be the task-irrelevant feature because it is generally more salient than orientation (e.g., Kristjansson, 2006), and therefore more difficult to ignore as the task-irrelevant feature, it appears that increasing the signal of the task-irrelevant feature *increased* the likelihood that people attended to that feature. Although it was unintentional, we may have increased the ease with which color was selected from Experiment 1 to Experiment 2 by reducing the number of items and thus increasing the likelihood that attending to the repeated color would allow subjects to quickly locate the target, either in the first group they attended or by quickly switching to the other group when the two items were identical. Additionally, by having four possible target colors in Experiment 3b versus two target colors in Experiment 3a, we may have pushed people to notice color repetitions more by increasing the heterogeneity of the display.  Others have demonstrated that increasing noise in the display encourages people to rely more on target repetitions than top-down guidance to find the target (e.g., Olivers & Meeter, 2006). Thus, repeating the target color may have helped people find the target more often in Experiment 3b versus 3a, resulting in greater color priming in Experiment 3b.

The increased color signal in Experiments 2 and 3b could also be linked to our finding that color priming was positively associated with extraversion and negatively associated with neuroticism in Experiment 2. Extraversion is typically associated with the motivational construct of *approach temperament*, which broadly refers to people who are driven by positive affect, a need for positive feedback, and otherwise rewarding stimuli (e.g., Elliot & Thrash, 2002). Conversely, neuroticism is related to the construct of *avoidance temperament*, a label for people who are highly sensitive to negative stimuli and punishment. In fact, these constructs may influence how visual attention is allocated; for instance, extraverts are slow to shift attention away from positive stimuli, whereas introverts (especially neurotic ones) are slow to shift attention away from negative stimuli (Derryberry & Dean, 2002). Although the stimuli in the current study had no explicit valence, either positive or negative, it is possible that extraverted participants found color to be the more attractive or rewarding feature in Experiment 2, causing them to have a particularly difficult time shifting their attention away from color repetitions. In contrast, neurotic participants may have attributed a negative valence to color repetitions, possibly because they found them distracting or harmful to performance, which could have pushed them to avoid processing the target color.

Of course, these post-hoc explanations are speculative and require further experiments to determine whether increasing the ease of selection of the a given dimension leads to greater priming for that feature. For example, would increasing the similarity of the possible task-irrelevant colors lead to less color priming (i.e., targets and distractors are either red or magenta)? Simply reversing the task-relevant and task-irrelevant features in the current experiments might also reduce task-irrelevant priming (i.e., task-relevant feature is color, task-irrelevant feature is orientation), since orientation is less salient than color in the periphery. It is also possible that increasing the salience of the task-relevant dimension matters; for instance, we may have observed greater orientation priming in Experiment 1 because targets were horizontal or vertical, orientations that are more salient than 45º orientations. Additionally, to further investigate the relationship between priming patterns and approach/avoidance temperament, it would be informative to associate certain feature repetitions with an actual reward or punishment (i.e., points for responding to color repetitions, points taken away for responding to orientation repetitions). Therefore, future research is necessary to determine the role of feature salience and motivation in both task-relevant and task-irrelevant feature priming.

## 7.3. Broader implications

Although the patterns of task-relevant and task-irrelevant feature priming effects in Experiments 2 and 3 were unexpected, they suggest that, while initial target selection tends to occur in an obligatory, object-based manner, the consequences of object-based attention are much more flexible than previously thought. Since there was a positive relationship between the amount of priming for orientation and color within subjects, this suggests that people processed task-relevant and task-irrelevant dimensions to a similar extent. In other words, there is no evidence that people consistently prioritized one dimension over the other in either Experiment 1 or 2. However, we also consistently observed significant priming for the task-irrelevant dimension independently of the task-relevant feature (i.e., when the task-relevant feature changed, but the task-irrelevant feature repeated), which suggests that once a task-irrelevant feature is co-selected, that feature can be modulated in a flexible manner. This idea is consistent with a recent study showing that task-relevant and task-irrelevant features are modulated independently in locations beyond the attended object (Lustig & Beck, in press). Together, these results indicate that object-based attention may ultimately rely on multiple feature-based processes, and that while co-selection of task-irrelevant features can occur, it also occurs in parallel with selection of the task-relevant feature.

Previous priming studies have focused on the importance of the task-relevant dimension (e.g., Kristjansson, 2006; Fecteau, 2007), emphasizing that what we attend to from trial to trial is primarily driven by our current task set, goals, etc. For instance, Fecteau (2007) found that cuing the task-relevant feature (color or shape) of an upcoming colored shape target significantly increased priming, but only for the task-relevant feature (e.g., repeating target color only speeded responses when the target-defining feature was color). However, in light of the current results, task-relevance clearly is not always the dominating factor in determining how we attend to things; we are also very susceptible to task-irrelevant features that are easy to select. This idea has implications for the field of visual attention in particular; although there is extensive research on the influence of task-relevance in processing salient distractor items (i.e., task set-dependent attentional capture, Folk & Remington, 1998), less is known about our susceptibility to high signal, task-irrelevant features of attended objects. Because task-irrelevant features are spatiotemporally associated with task-relevant features (i.e., they co-occur in the same object), task-irrelevant features may be more difficult to ignore even if they are very different from the current task set.

Additionally, the finding that VSTM capacity is predictive of the amount of consecutive priming for task-irrelevant color is consistent with previous findings that low OSPAN participants were more surprised by target changes after a string of repeated targets than high OSPAN participants (Brumback et al., 2005). Importantly, in both of these tasks, specific target values occurred at chance (i.e. 50% probability), so there was no benefit overall to prioritizing any one feature or target. Thus, these results imply that people with poor VSTM capacity, goal maintenance or other executive functioning abilities are more likely to be influenced by spurious repetitions of events that are actually meaningless. The implications of this finding may thus extend beyond studies of perception and attention to higher-level processes such as decision-making; for instance, phenomena such as the gambler's fallacy (expectations of a change increase as a string of repetitions grows longer and longer) or rash economic decisions based on recent trends in the stock market may be based on a similar limitation in the ability to resist seemingly meaningful patterns in recent memory.

Ultimately, although people may generally rely on top-down guidance to attend to objects, task-relevance can only take us so far; we are also highly influenced by salient, bottom-up properties of objects. In particular, people may be drawn to obvious, systematic patterns in the visual world, regardless of task-relevance. However, rather than reflecting a constraint of the visual system, our ability to tap into salient visual patterns may actually reflect a flexible attentional system that uses whatever information is available to make sense of the visual world.

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