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Previous Experiences Drive Attention

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PREVIOUS EXPERIENCES DRIVE ATTENTION

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You can enter God's Kingdom only through the narrow gate. The highway to hell is broad, and its gate is wide for the many who choose that way. But the gateway to life is very narrow and the road is difficult, and only a few ever find it (Matthew 7:13-14).

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Abstract

Traditionally, the allocation of attention was understood within goal-driven and stimulus-driven factors. However, the traditional approach cannot fully account for the mechanism of attentional orienting. Instead, a growing body of evidence shows that previous search experiences, irrelevant to both goal-driven and stimulus-driven factors, influence attentional allocation. For example, when contexts predict information of targets, the contexts guide attention toward the stimuli having the information predicted by the contexts: contextual cueing. In addition, more valuable stimuli attract more attention: value-driven attentional capture. However, two critical issues are present. First, contextual cueing has been found largely when the contexts and the target information predicted by the contexts are in the spatial dimension. Second, it is unclear how the values of the items are determined to guide attention. Accordingly, the dissertation investigates these issues to further understand the mechanism of attentional allocation beyond the traditional perspective. The results of the dissertation suggest that more attention is required for non-spatial context-driven search than spatial context-driven search and that value-driven attention is on the basis of prospect theory. In conclusion, the dissertation further clarifies the mechanism by which previous experiences affect the allocation of attention.

Introduction

Selective attention is the process of selecting particular stimuli for further processing (Moran & Desimone, 1985). Traditionally, the attentional selection process was known to be influenced by bottom-up (stimulus-driven) and top-down (goal-driven) mechanisms (Wolfe, 1994). In the bottom-up mechanism, attentional selection is determined by stimuli's physical properties regardless of the task-goal. For example, a single red object among many green objects is salient and so attracts attention involuntarily. In the top-down mechanism, attention is guided to stimuli that match the current task-goal of the observer. For example, when a task-goal is to search for a red object, top-down biasing signals to the neurons representing the perceptual processing of red (Duncan & Humphreys, 1989). Therefore, red stimuli receive attentional priority. However, selective attention is not always explained by the task goal and physical saliency (Awh, Belopolsky, & Theeuwes, 2012).

Experience-driven Search

Growing evidence suggests that previous experiences can also guide attention (Awh et al., 2012). A core feature of the experience-driven search is that attention is guided by neither a task goal nor stimuli saliency but knowledge accumulated from previous trials. Therefore, the scope of the experience-driven search is broad. However, in attentional orienting literature, there are hot topics where attentional allocation is explained by neither a task goal nor stimuli saliency: contextual cueing and value-driven attentional capture. Therefore, the direction of the dissertation focuses on contextual cueing and value-driven attentional capture. Although numerous studies have explored these topics and replicated the original main findings, there are still critical issues that have not been explored in the previous literature. Therefore, exploration

of the mechanisms of contextual cueing and value-driven attentional capture would allow further understanding of how previous experiences drive attention.

Contextual cueing (Chun & Jiang, 1998) shows that previously encountered-search displays guide attention to targets. However, contextual cueing was replicated mainly in the spatial dimension but rarely in the non-spatial dimension. Value-driven attentional capture (Anderson, Laurent, & Yantis, 2011) shows that stimuli previously associated with rewards receive attentional priority. Therefore, it is essential to understand both reward value (how reward values are represented and linked to the stimuli) and selective attention (the effect of the valuable stimuli capturing attention). While the latter has been explained clearly (Rusz, Le Pelley, Kompier, Mait, & Bijleveld, 2020), the former is little known because it may require economic perspectives that have not yet been considered. Thus, an interdisciplinary approach may be needed to understand value-driven attentional capture. Accordingly, the dissertation directly addresses these issues by investigating value-driven attentional capture using interdisciplinary perspectives and contextual cueing in the non-spatial dimension.

Experience-driven Search: Contextual Cueing

Previous experiences guide attention to visual targets based on knowledge of contexts (e.g., multiple stimuli occurring concurrently or existing in the immediate vicinity) where the targets tend to appear. When searching for targets in the visual environment, regularities in the environment can be learned overtime and used to direct attention to the target more quickly in the future (e.g., ketchup with French fries, a light switch near a door). This contextual guidance of attention is explained by neither a task-goal nor stimuli saliency and is directly examined in the contextual cueing literature (e.g., Chun & Jiang, 1998, 1999).

Contextual cueing is an effect of selective attention that shows that characteristics (e.g., configuration, shape) of the distractors predict characteristics (e.g., a location, shape) of the search target. For example, in the Chun and Jiang study (1998), participants encountered repeatedly the same spatial configurations of a target (a rotated T) and distractors (rotated Ls) on half of the trials. On the other half of the trials, the configurations were novel. Critically, search became gradually faster in the repeated configurations than in the novel configurations. This finding suggests that participants learned the associations between the configurations of the distractors and the locations of the targets in the repeated configurations. Therefore, detection of the repeated configurations guided attention to the predicted locations of the targets. This is referred to as *spatial* contextual cueing.

What is less well understood is if contextual cueing is specific to spatial contexts or if it can also occur for contexts defined by identity. Contextual cueing has been found when shapes of distractors predict the shape of targets (Chun & Jiang, 1999). The locations of all search items (a target and distractors) were random. However, while the identities (various abstract shapes) of all items was consistent on the repeated condition trials (e.g., shapes A (distractor), B (distractor), C (distractor), D (distractor), and E (target) repeatedly appear in different locations), the identities were not consistent on the novel condition trials. Search was faster in the repeated than novel condition trials. This finding suggests that the shapes of distractors guided attention to the predicted shape of the targets. This is referred to as *non-spatial* contextual cueing.

Over two decades, while spatial contextual cueing was replicated in many studies after the first demonstration of Chun and Jiang (1998), non-spatial contextual cueing was rarely found after the first demonstration of Chun and Jiang (1999; see for a review, Goujon, Didierjean, & Thorpe, 2015). In addition, it was directly shown that non-spatial contextual cueing is hard to

replicate compared to spatial contextual cueing (Endo & Takeda, 2004). This replication difficulty is surprising given basic abilities to attend to non-spatial features (Lamy & Kristjánsson, 2013). Accordingly, it is important to understand why non-spatial contextual cueing is seldom found in the literature. One possibility is that the non-spatial contextual cueing requires more attention than spatial contextual cueing. I explored the hypothesis in the modified pre-cueing paradigm in Chapter 1. In the paradigm, shape of contexts predicts color of targets. The shape and color are considered task-irrelevant because target-defining features are the identity of letters (Z and N). Nevertheless, if the contexts are used to guide attention, the contexts would facilitate attention to colors predicted by the contexts. This facilitation is measured by cueing effects: the color cue whose color is predicted by contexts captures attention more than the non-predicted color cue; therefore, targets at the cued locations are detected faster than targets at the un-cued locations. Chapter 1 showed that this non-spatial context-driven search effect can occur only when cognitive resources increase. This finding suggests that context-driven search requires attentional resources, and more attentional resources may be needed in non-spatial than spatial contextual cueing.

Experience-driven Search: Value-driven Attentional Capture

According to value-driven attentional capture, previous experiences that associated value (e.g., reward) with stimuli lead to the valuable stimuli receiving attentional priority. For example, the Anderson et al. study (2011) shows that stimuli previously associated with more rewards attract more attention. Their study consisted of two phases, training and test. In the training phase, participants learned associations between stimuli and reward value. Participants searched for red and green circles: a red or green target was randomly presented on each trial. Participants

responded based on whether the orientation of a line inside the target was vertical or horizontal. When the response was correct, reward was given. Critically, red targets led to more reward than green targets (color/reward association counterbalanced). Therefore, while red was associated with a high reward value, green was associated with a low reward value.

In the test phase, it was tested whether the color/reward association influences attentional allocation. Participants searched for the unique shape target to report the orientation of the line inside the shape. Therefore, color became a task-irrelevant dimension. Also, participants were informed that no reward would be given in the test phase. On some trials, one of the distractors was either red or green. If the color/reward association from the training phase influences attentional allocation, red distractors should capture attention more than green distractors. Then, search will be slower when red distractors are presented than when green distractors are presented. This was what the authors found, demonstrating that valuable stimuli capture attention. The value-driven attentional capture effect has since been validated in many behavioral and brain studies (Anderson, 2016; Rusz, Le Pelley, Kompier, Mait, & Bijleveld, 2020).

Value influences not only selective attention (value-driven attentional capture) but also judgement and decision making (Prospect theory (Kahneman & Tversky, 1979): an economic theory that describes how people choose between different prospects). Kahneman and Tversky proposed the value-function of Prospect theory to explain how value is *actually* represented for judgement and decision-making. The value-function of Prospect theory was extensively demonstrated and has been applied to real life economic issues such as marketing (Barberis, 2013). However, little was known about whether value-driven attentional capture also operates on the basis of the value-function of Prospect theory. In other words, can Prospect theory be applied to selective attention?

The question was not previously explored and so remained unsolved. Also, the paradigm used in the previous value-driven attentional capture literature cannot solve the issue (Anderson, 2016). Thus, I developed a new paradigm by combining Prospect theory and the value-driven attentional capture paradigm. Accordingly, I investigated whether reference dependence (Chapter 2) and diminishing sensitivity (Chapter 3) of Prospect theory extends to the selective attention stage. According to reference dependence, value is determined by a reference point; therefore, relative value (e.g., higher), but not absolute value (e.g., $5), is critical. According to diminishing sensitivity, a marginal impact of a change gradually decreases from a reference point of zero; therefore, 100-point stimuli, paired with 1-point stimuli, attract attention more than 1000-point stimuli, paired with 901-point stimuli. These findings suggest that prospect theory extends to selective attention.

Chapter 1: Non-Spatial Context-Driven Search

This chapter previously appeared as [Kim and Beck (2020). Non-spatial context driven search. Attention, Perception & Psychophysics]. It is reprinted by permission of Sunghyun Kim—see the permission letter (Appendix D) for proper acknowledgment phrase.

Non-Spatial Context-Driven Search

The visual sensory system receives a great deal of information, but attentional limitations severely restrict the amount of information processed beyond a sensory level. Attention is not only passively oriented by bottom-up saliency of objects, but also actively oriented by top-down attentional control settings of observers (Wolfe, 1994). Accordingly, it is important to understand how and when top-down attentional control settings are formed and when they are used (Awh, Belopolsky, & Theeuwes, 2012). Top-down attentional control settings for target characteristics can be formed based on a learned context/characteristic association, but this has most commonly been reported for spatial characteristics (Brockmole et al., 2006; Chun, 2000; Chun & Jiang, 1998, 2003; Jiang & Wagner, 2004; Olson & Chun, 2002; Vaidya, Huger, Howard, & Howard, 2007). The present study explores attentional control settings for non-spatial characteristics formed through incidental associative learning. In particular, when shape contexts predict the color of targets, can the shape contexts trigger an attentional control setting for the predicted color?

Visual scenes often contain structured properties of repeated patterns and regularities that may be used to guide attention. The structured properties can be extracted and learned without intention through an incidental learning process (Baker, Olson, & Behrmann, 2004; Beck, Angelone, Levin, Peterson, & Varakin, 2008; Beck, Goldstein, van Lamsweerde, & Ericson, 2018; Fiser & Aslin, 2005; Kirkham, Slemmer, & Johnson, 2002; Leber, Gwinn, Hong, & O'Toole, 2016; Otsuka, Nishiyama, Nakahara, & Kawaguchi, 2013; Turk-Browne, Jungé, & Scholl, 2005). Accordingly, while attentional control settings are largely considered to be explicitly formed (Folk, & Remington, 1998; Wolfe, 1994), they can also be established for contexts through incidental associative learning: *context-driven search* (Brockmole, Castelhano,

& Henderson, 2006; Chun, 2000; Chun & Jiang, 1998, 1999; Endo & Takeda, 2004; Jiang & Chun, 2001; Torralba, Oliva, Castelhano, & Henderson, 2006). Context-driven search occurs when a learned association between a context and a target characteristic allows the context to trigger an attentional control setting for the target characteristic.

Contextual cueing (Brockmole et al., 2006; Chun, 2000; Chun & Jiang, 1998, 2003; Jiang & Wagner, 2004; Olson & Chun, 2002; Vaidya, Huger, Howard, & Howard, 2007) is a specific example of spatial context-driven search in which the configuration of distractors predicts the location of a target. A typical methodology (e.g., Chun & Jiang, 1998) of the spatial context-driven search is that configurations of distractors are occasionally repeated (repeated contexts) or not (novel contexts). The target location is predicted by the configuration of the distractors in the repeated contexts but not in the novel contexts, allowing faster detection of a search target for the repeated than novel contexts despite a lack of awareness of the associations between contexts and target locations. Incidental learning of the associations of the spatial characteristics leads to the repeated contexts triggering attentional control settings for target locations predicted by the contexts (Chun & Jiang, 1998).

The present study investigated whether context-driven search occurs when shape contexts predict the target's color: *non-spatial context-driven search.* Evidence of shape contexts guiding attention to a color predicted by the contexts (e.g., Anderson, 2015; Gozli et al., 2014) is not as abundant as spatial context-driven search (Brockmole et al., 2006; Chun, 2000; Chun & Jiang, 1998, 2003; Jiang & Wagner, 2004; Jiang, Sigstad, & Swallow, 2013; Olson & Chun, 2002; Rosenbaum & Jiang, 2013; see Goujon, Didierjean, & Thorpe, 2015 for review). This is somewhat surprising given the ability to form attentional control settings for non-spatial features such as color and shape (Lamy & Kristjánsson, 2013; Maunsell & Treue, 2006). The imbalance

in the amount of evidence supporting spatial and non-spatial context-driven search may be because non-spatial context-driven search may require more cognitive resources than spatial context-driven search. Although context-driven search requires cognitive resources (Jiang & Leung, 2005; Manginelli et al., 2013), non-spatial context-driven search appears to only be found in situations that encourage participants to devote *additional* cognitive resources to processing the shape/color associations (e.g., Anderson, 2015; Gozli et al., 2014).

The use of learned associations to guide attention requires cognitive resources (e.g., attention and working memory). Jiang and Leung (2005) demonstrated that although attention to contexts is not necessary for the associative learning in spatial context-driven search, attention is necessary for the contexts to trigger an attention bias (expression of the associative learning). Similarly, Manginelli et al. (2013) suggested that working memory resources are not required for the associative learning in the spatial context-driven search but are required for the expression of the previously learned associations. These findings suggest that although learning of the association may occur, spatial context-driven search may not occur if limited cognitive resources prevent processing of the contexts.

In order to use a learned shape/color association to guide attention during search toward the color predicted by the shape context, the need for cognitive resources might be greater than what has been shown for spatial context-driven search. Previous studies showing shape contexts triggering attentional control settings for color predicted by the contexts included methodological factors that could have increased cognitive resources for the shape/color association (Anderson, 2015; Gozli et al., 2014). In Anderson (2015), the associations between the shape contexts (background images) and color involved reward learning. Reward facilitates associative learning by prioritizing the reward-associated information (Hyman, Malenka, & Nestler, 2006). Thus, the

reward learning would increase cognitive resources for the shape/color associations (Anderson, 2015). In Gozli et al., (2014), the shape contexts did not guide attention to the shape-predicted color when the predictive shape (e.g., 'S') and predicted color (e.g., red) features were presented separately in different objects. However, they guided attention when both the shape and color features were presented in a single object (e.g., red 'S'). The conjunctive presentation could have increased cognitive resources allocated to the shape/color association because the shape context ('S') was the target. That is, the shape context would receive attention regardless of the conjunctive presentation or separate presentation because the shape was the target. However, the color would receive less attention in the separate presentation than the conjunctive presentation because the color (non-target) would have attentional benefit when the color was presented with the shape (target) in a single object compared to when it was presented separately (Gozli et al., 2014). This is in line with research showing that attention to any one property of an object can facilitate attention to other properties of the object (Kahneman, Treisman, & Gibbs, 1992). In the spatial context-driven search, however, such boosts for cognitive resources were not necessary (Brockmole et al., 2006; Chun, 2000; Chun & Jiang, 1998, 2003; Jiang & Wagner, 2004; Jiang, Sigstad, & Swallow, 2013; Olson & Chun, 2002; Rosenbaum & Jiang, 2013). This discrepancy indicates that the non-spatial context-driven search may need more cognitive resources than the spatial context-driven search. In other words, to observe a shape context triggering an attentional control setting for a color associated with the shape, a factor that increases cognitive resources for the shape/color associations may be necessary.

The current study investigated whether a shape context can trigger attention for a color predicted by the context. Considering that a boost in cognitive resources may be needed to observe non-spatial context-driven search, we inserted two mismatch trials as a facilitator factor

that increases cognitive resources to the shape/color association. The mismatch trials violated a previously consistent shape/color association. For example, square contexts predicted red targets, and circle contexts predicted green targets on all trials (match trials) except for the two mismatch trials. In the two mismatch trials, the associations were different (e.g., square/green, circle/red) from the match trials. The sudden conflict with the previous associations should increase cognitive resources for the shape/color association by inducing the exploratory attention processes (Easdale, Le Pelley, & Beesley, 2019; Hall & Pearce, 1982; Pearce & Bouton, 2001; Pearce & Hall, 1980; Swan & Pearce, 1988) and conflict-driven cognitive control (Botvinick, Cohen, & Carter, 2004; Egner, 2007; Mayr, Awh, & Laurey, 2003).

The mismatch trials would increase cognitive resources for the shape/color association by inducing exploratory attention. In associative learning, a sudden violation of the previously learned association between the predictor and outcome can increase attention to the predictor (Easdale, Le Pelley, & Beesley, 2019; Griffiths, Johnson, & Mitchell, 2011; Hall & Pearce, 1982; Pearce & Bouton, 2001; Pearce & Hall, 1980; Swan & Pearce, 1988; Wills, Lavric, Croft, & Hodgson, 2007; Wilson, Boumphrey, & Pearce, 1992). Specifically, the violation brings about uncertainty about the previous association. Then, an effort is made to resolve the uncertainty through exploratory attention. Exploratory attention increases attention to the uncertain stimuli. Therefore, the mismatch trials, which violate the previous associations, would induce exploratory attention to resolve the shape/color association, and so cognitive resources allocated to the shape/color association should increase.

The mismatch trials could also lead to an increase in conflict-driven cognitive control, which would increase the cognitive resources allocated to the shape/color association. Detection of cognitive conflict induces an up-regulation in cognitive control (Egner, 2007). The increased

cognitive control leads to an increase in cognitive resources for task-relevant information. This conflict-driven cognitive control effect occurs in various tasks (e.g., Simon, Stroop, Flanker tasks) and stimuli (Egner, 2007; Egner & Hirsch, 2005). In the Stroop task, for example, the Stroop effect decreases after an incongruent trial where conflict occurs between a word meaning and the color of the word compared to after a congruent trial where no conflict occurs. This decrease in the Stroop effect is attributed to conflict from the incongruent trial leading to an increase in cognitive control. If the shape/color association is learned in the current study, the mismatch trials could introduce conflict by violating the learned association. Therefore, we predicted that the mismatch trials would enhance cognitive control, and so cognitive resources for the shape/color association would increase.

The Present Study

The purpose of the present study was to investigate whether contexts predicting the color of targets can guide attention by triggering an attentional control setting for the target color (non-spatial context-driven search). To examine this non-spatial context-driven search, we developed the contextual pre-cueing paradigm. This paradigm is based off of the pre-cueing paradigm of Cosman and Vecera (2014) in which an attentional control setting for a particular color is formed through incidental learning of statistical information. Specifically, in Cosman and Vecera's (2014) pre-cueing paradigm, a search target was defined as the identity of a letter (e.g. "H" or "B"). Two letters were presented in either red or green font, one on each side of a central fixation marker, and participants reported the identity of the target as quickly as possible. During the learning phase, unbeknownst to participants, one target color was more probable than the other (e.g., 80% red, 20% green). During the test phase, target color was no longer biased. Results from the test phase showed that cues presented prior to the letter stimuli captured attention more

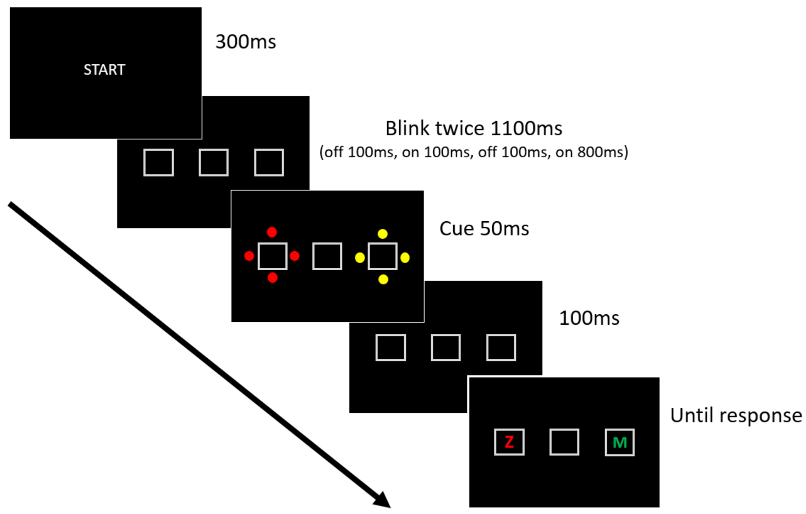
when the cues were the probable target color (red cues) than when they were the less probable target color (green cues), suggesting that participants incidentally formed attentional control setting for the probable target color (Cosman & Vecera, 2014).

The current study expanded on this finding by creating a contextual pre-cueing paradigm in which one of two contexts (square placeholders and circle placeholders) was randomly presented from trial to trial. Participants reported if a Z or an N was presented. The targets (Z or N) appeared in one of two target colors (red or green) that were equally probable. The context (square or circle) predicted the color of the search target, allowing us to test if an attentional control setting for a specific color can be triggered by an associated context (i.e., 'context A = red target' and 'context B = green target' associations induce searching for red under context A and green under context B). If non-spatial context-driven search occurs, cues whose color is the same as the context-predicted target color (red cues under context A and green cues under context B) would capture attention more than cues whose color is not the same (green cues under context A and red cues under context B). Accordingly, the cueing effect (faster responses for targets appearing at a cued than un-cued location) would be larger for the context-predicted color cues than non-predicted color cues.

Experiment 1

Experiment 1 investigated whether an attentional control setting for a color can be flexibly adopted depending on a given context as the result of incidental learning of the associations between contexts and color of targets. In the contextual pre-cueing paradigm, participants were asked to find letters Z and N, only one of which was presented on each trial (see Figure 1-1). The target letter was colored in either red or green and the distracter letter was colored in the other color. Critically, each target color was paired with a particular context. For

example, the search target was red when the shape of the fixation marker and placeholders was square, and it was green when the shape was a circle. Participants were not informed of the shape/color association.



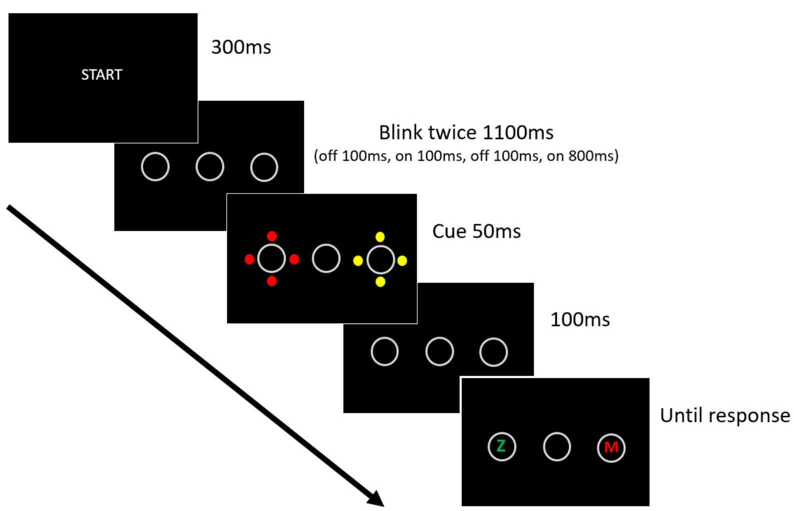


Figure 1.1**.** Examples of the square (top) and circle (bottom) contexts.

A cue color was either red or green, and the other location was always yellow. In the examples, when the context was square (circle), the color of the targets (Z or N) was red (green). Therefore, a red cue was the predicted color cue in the square context, but the non-predicted color cue in the circle context. In addition, a valid (invalid) cue was when locations between a cue and target were the same (different). Therefore, in the examples, both red cues in the square and circle contexts are valid cues.

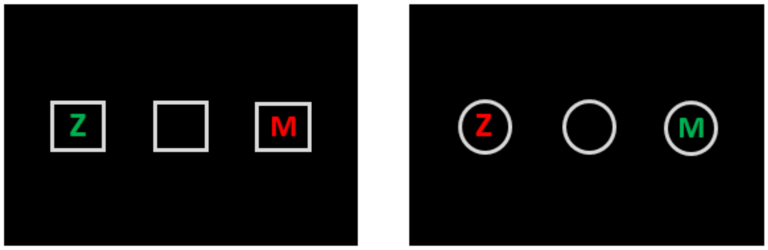


Figure 1.2**.** Examples of the reversed color mismatch trials used in Experiment 1.
These examples were when the original associations (match trials) were square-red and circle-green.

If the contexts (shape of the fixation marker and placeholders) trigger attentional control settings for the color predicted by the contexts, predicted color cues (i.e., cues whose color is the same as target color predicted by a given context) would better capture attention than the non-predicted color cues (i.e., cues whose color is different from target color predicted by a given context). For example, when the square context was paired with red targets, red cues were predicted color cues with the square context but non-predicted color cues with the circle context. Therefore, when there is an attentional set based on the context-target color association, predicted color cues should capture attention more than non-predicted color cues, leading to a cueing effect (shorter response time when cues validly cue the target location than when the cues are invalid) that is larger for the predicted than non-predicted color cue. Accordingly, a larger cueing effect for predicted color than non-predicted color cues is indication of a non-spatial context-driven search effect.

We predicted that non-spatial context-driven search may not occur without a violation in the association that could increase cognitive resources allocated to the shape/color association. Following learning trials in which a given context was always paired with the same target color, two mismatch trials were added in which the context-color association was violated. Mismatch

trials should increase exploratory attention (Easdale, Le Pelley, & Beesley, 2019; Griffiths, Johnson, & Mitchell, 2011; Hall & Pearce, 1982; Pearce & Bouton, 2001; Pearce & Hall, 1980; Swan & Pearce, 1988; Wills, Lavric, Croft, & Hodgson, 2007; Wilson, Boumphrey, & Pearce, 1992) and cognitive control (Egner, 2007) and therefore, may provide the cognitive resources necessary for the use of the learned shape-color associations to guide attention. Furthermore, we predicted that the effect triggered by the mismatch trials would be short lived. The exploratory attention and conflict-driven cognitive control are not long lasting (Rey-Mermet & Meier, 2017; Kaye & Pearce, 1984). Thus, the two mismatch trials would facilitate the expression of the non-spatial context-driven search by temporarily increasing cognitive resources to the shape/color association. We predicted that epochs of trials just before the mismatch trials would not show a larger cueing effect for the predicted than non-predicted color cue, but epochs of trials just after the mismatch trials would show the effect.

Method

Participants. Twenty-four undergraduate students participated for course credit (21 females, average age = 18.25 years, SD = .61). All had normal or corrected-to-normal vision. Sample size was on the basis of the Gozli et al. study (2014) where cue validity differences between cue colors, which is the indication of a non-spatial context-driven search effect, had an effect size of η_p^2 = .33. G power analysis (a power of 0.80, an alpha of 0.05, effect size of η_p^2 = .33) indicated the minimum sample size of 19.

Apparatus. Stimuli were presented on a monitor (20 inch) of a MacOS computer. The distance between the participants and monitor was approximately 60 cm but was not constrained. Experiments were programmed using MATLAB and Psychophysics Toolbox software.

Stimuli, procedure, and design. All stimuli were presented on a black background. For the square context trial (see Figure 1-1), the fixation marker (1.3° each side of a square) and placeholders (1.3° each side of a square) were squares. For the circle context trial (see Figure 1-1), the fixation marker (1.4° diameter) and placeholders (1.4 ° diameter) were circles. At the beginning of each trial, a text message of 'START' was presented for 300 ms at the center of a black screen. Then, after a blank, all black, display for 100 ms, the fixation marker and placeholders (two circles or two squares on either side of the fixation marker) were presented for 100 ms, followed by another blank display of 100 ms. The fixation marker and placeholders then reappeared and after 800ms. The cue display was presented for 50 ms, where one of the placeholders was cued with four red (RGB: 255, 0, 0) or green (RGB: 0, 255, 0) small dots around the cued placeholder, and the other place holder always had four yellow dots (RGB: 255, 255, 0). After the cue disappeared, the fixation marker and empty placeholders remained on screen for 100 ms. Then, one of the search targets (Z and N) was presented in one of the placeholders and one of the distractors (M, V, and X) was presented in the other placeholder until a response was made. The participants were asked to find and identify the search target by pressing the corresponding key (Z or N) as quickly and accurately as possible. Feedback was provided directly after a response was made for slow or incorrect responses. If a correct, but slow, response was made (response time greater than 1000 ms), a message of 'too slow' was presented at the center of the screen for 700 ms. If an incorrect response was made regardless of response time, a message of 'wrong' was presented at the center of the screen for 700 ms. If a correct response was made before 1000 ms, no feedback was presented, and the next trial began. Participants were explicitly informed that the shape of the fixation marker and placeholders

would change between square and circle. However, they were not informed of any possible association between the shape and the target color.

The experiment consisted of a practice session (20 trials; participants had opportunities to ask questions during and right after practice), an experiment session (800 match trials[1], 2 mismatch trials, and 128 match trials in sequence), and a post-test questionnaire. A self-paced break was given after the 800th trial of the experiment session. Two mismatch trials were inserted on the 801st and 802nd trials. In the match trials, for half of the participants, the color of the search target was always red for the square context, and the color of the search target was always green for the circle context. For the other half of participants, this association was reversed. The distractor was always the other color (i.e., if the target was red, the distractor was green).

For each context, the cue color was equally likely to be either the context-predicted target color (predicted color cue) or the context-predicted distractor color (non-predicted color cue). Therefore, within each context, the color of the cue was equally often either red or green. When the cue color was the same as the target color, which was predicted by a context, the cue was the predicted color cue. When the cue color was not the same as the predicted target color but was the same as the predicted distractor letter color, the cue was the non-predicted color cue. Note that although contexts predict the color of both the target and distractor letters (e.g., target and distractor colors are always red and green respectively in the square context), the predictive relationship (context-predicted color, context-non-predicted color) was based on the association between the contexts and target color. For example, in the square-red target association, the

[1] The first 12 of 812 trials were excluded because every 16 trials contained an equal number of trials for each condition and this was applied from the beginning of the practice session, which had 20 trials. The exclusion allowed the analysis of the 800 trials containing an equal number of trials for each condition.

predicted color cue was red (target color in the square context) and the non-predicted color cue was green (distractor color in the square context).

Two critical factors were manipulated across trials: cue validity (valid or invalid cue), and cue color (predicted or non-predicted color cue). Valid cues were presented at the same location as the target. Invalid cues were presented at the other location. Within every 16 consecutive trials in the practice and experiment sessions, contexts (square or circle), cue color (red or green), cue location (left or right), and target location (left or right) were fully crossed, so that every 16 trials included 4 valid predicted color cue trials, 4 valid non-predicted color cue trials, 4 invalid predicted color cue trials, and 4 invalid non-predicted color cue trials. A target type (Z or N) and distractor type (M, V, and X) were randomly selected on each trial.

The two mismatch trials had reversed context-color associations (Figure 1-2). For example, if original associations were square context-red target and circle context-green target, reversed associations were square context-green target and circle context-red target. Immediately after the experiment, a post-test awareness question was given to check awareness of the association between contexts and color of targets. This was an open-ended question in which participants were asked to describe any patterns, in terms of the shape of the fixation and placeholders that they had noticed.

Results

Analyses of variance (ANOVAs) were conducted on the mean of RT with cue validity (valid or invalid cue) and cue color (predicted or non-predicted color cue) as within-subjects variables for each epoch. Each epoch had 48 trials (12 valid predicted color cue, 12 invalid predicted color cue, 12 valid non-predicted color cue, and 12 invalid non-predicted color cue).

The 705th – 752nd trials, 753rd – 800th trials, 803rd – 850th trials, and 851st – 898th trials belonged to epoch 1, 2, 3, and 4, respectively. The two mismatch trials were presented only on 801st and 802nd trials. The two mismatch trials were excluded from the analysis (Pearce & Hall, 1980). The analyses were restricted to these 4 epochs to check for a cueing effect before and after the mismatch trials.

It should be noted that the epoch size (48 trials) was used so that there were an equal number of each trial type in each epoch and was determined based on initial visual inspection of the results of Experiment 1. The post-decision of the epoch size was used because although the exploratory attention and conflict-driven cognitive control are not long lasting (Rey-Mermet & Meier, 2017; Kaye & Pearce, 1984), the length of them in the methodology of the present study was unknown. The epoch size of 48 trials was maintained for the data analysis in Experiments 2 and 3 to confirm that the epoch size could be used to replicate the effect.

RT (response time) was measured from the onset of a target until a response was made. Overall, 15.49% of trials were excluded from analysis: RTs shorter than 125 ms (0.07%), RTs longer than 1000 ms (4.94%), and incorrect responses (10.47%). The 1000 ms exclusion was based off of criteria used in Cosman and Vecera (2014).

RT. To examine if the non-spatial context-driven search effect occurred only immediately after the mismatch trials, ANOVAs with cue color and validity were conducted for epochs 1-4 where epochs 1 and 2 occurred just before the mismatch trials and epochs 3 and 4 occurred just after the mismatch trials. In epoch 1, the main effects of cue color and validity were not significant, $F(1, 23) = 1.17$, $p = .29$, $\eta_p^2 = .05$, and $F(1, 23) = 2.32$, $p = .14$, $\eta_p^2 = .09$, respectively. The interaction between cue color and validity was also not significant, $F(1, 23) =$

2.00, p = .17, η_p^2 = .08. In epoch 2, the main effects of cue color and validity were not significant, $F(1, 23) = 1.94$, p = .18, η_p^2 =.08, and $F(1, 23) < .01$, p = .96, η_p^2 <.01, respectively. The interaction between cue color and validity was also not significant, $F(1, 23) = .24$, p = .63, η_p^2 = .01. In epoch 3, the main effects of cue color and validity were not significant, $F(1, 23)$ =.18, p = .68, η_p^2 =.01, and $F(1, 23) = 1.00$, p = .76, η_p^2 < .01, respectively. However, the interaction between cue color and validity was significant, $F(1, 23) = 5.38$, p = .03, η_p^2 = .19, due to a larger validity effect for the predicted than non-predicted color cue (the non-spatial context-driven search effect). Post hoc tests further revealed that the predicted color cue produced a significant validity effect [19 ms; $t(23) = 2.31$, p = .03], while the non-predicted color cue did not [-14 ms; $t(23) = -1.16$, p = .26]. In epoch 4, the main effects of cue color and validity were not significant, $F(1, 23) = .80$, p = .38, η_p^2 = .03, and $F(1, 23) < .01$, p = .98, η_p^2 < .01, respectively. The interaction between cue color and validity was not significant, $F(1, 23) = .72$, p = .40, η_p^2 = .03. The cue validity effect (invalid RTs – valid RTs) for each type of cue and each epoch is reported in Figure 1-3 (see Table 1-1 for invalid and valid RTs).

The lack of an interaction between cue color and cue validity in epochs 1 and 2 suggests that the non-spatial context-driven search effect did not occur even after hundreds of match trials. To further confirm this, new ANOVAs with cue color and cue validity as within subject factors were conducted on epochs of 80 trials (1-80, 81-160, 161-240, 241-320, 321-400, 401-480, 481-560, 561-640, 641-720, and 721-800 trials; see Figure 1-3). However, no significant interactions between cue color and cue validity (no non-spatial context-driven search effect) were found in any of the epochs (all *ps* > .19; see Appendix A for a table of the ANOVA values).

Accuracy. None of the interactions or main effects of cue color and validity were significant in any of the epochs. In epoch 1, the main effects of cue color and validity were not significant, $F(1, 23) = 1.48$, $p = .23$, $\eta_p^2 = .06$, and $F(1, 23) = 1.95$, $p = .17$, $\eta_p^2 = .07$, respectively. The interaction between cue color and validity was not significant, $F(1, 23) = .01$, $p = .90$, $\eta_p^2 < .01$. In epoch 2, the main effects of cue color and validity were not significant, $F(1, 23) = .34$, $p = .56$, $\eta_p^2 = .01$, and $F(1, 23) = .15$, $p = .69$, $\eta_p^2 < .01$, respectively. The interaction was not significant, $F(1, 23) = 3.24$, $p = .08$, $\eta_p^2 = .12$. In epoch 3, the main effects of cue color and validity were not significant, $F(1, 23) = .77$, $p = .38$, $\eta_p^2 = .03$, and $F(1, 23) = .14$, $p = .71$, $\eta_p^2 < .01$, respectively. The interaction was not significant, $F(1, 23) = .33$, $p = .57$, $\eta_p^2 = .01$. Furthermore, Bayes Factor (BF_{01}) = 3.2 indicated that the null was 3.2 times more likely than the interaction, supporting the non-spatial context-driven search effect in RT was not due to speed-accuracy tradeoff. In epoch 4, the main effects of cue color and validity were not significant, $F(1, 23) = .59$, $p = .45$, $\eta_p^2 = .02$, and $F(1, 23) = 2.04$, $p = .16$, $\eta_p^2 = .08$, respectively. The interaction between cue color and validity was also not significant, $F(1, 23) = 1.14$, $p = .29$, $\eta_p^2 = .05$ (see Table 1-2).

Awareness Question. No participant reported noticing the association between the context and color of the target.

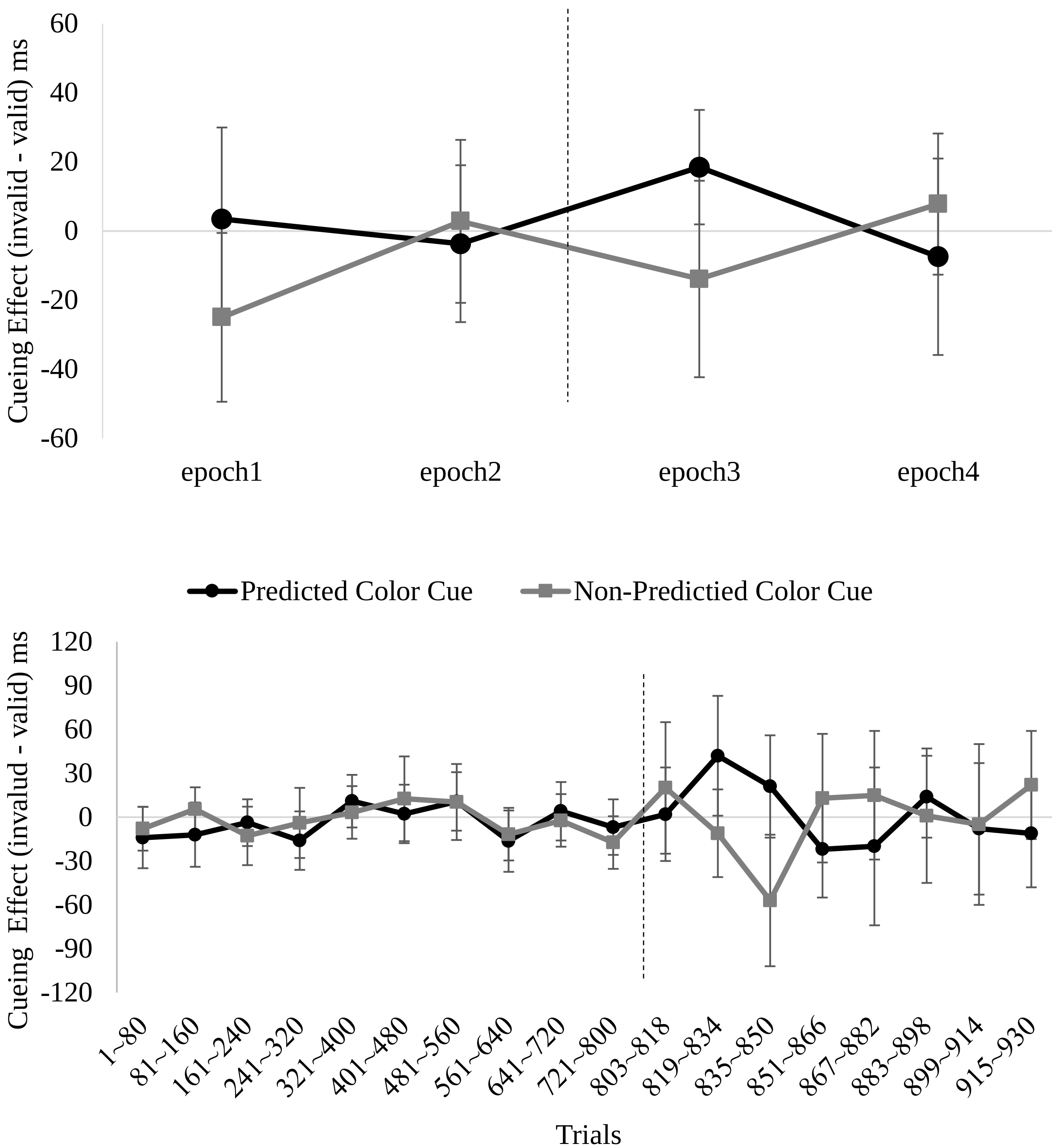


Figure 1.3**.** Results of Experiment 1.

In the top graph, each of epochs 1-4 includes 48 trials and across the following range of trials: 705-752, 753-800, 803-850, and 851-898, respectively. The bottom graph is the data in bins of 80 trials until the mismatch trials and then bins of 16 trials after the mismatch trials. The mismatch trials occurred between epochs 2 and 3, on trials 801 and 802 (see dashed black vertical line). Error bars represent 95% confidence intervals.

Table 1.1. Mean Response times and Standard Error of the Mean (in Milliseconds) as a Function of Epoch, Cue Color, and Cue Validity in Experiment 1.

	Predicted color		Non-predicted color	
	Valid	Invalid	Valid	Invalid
Epoch 1	594 (11)	598 (12)	600 (12)	575 (9)
Epoch 2	595 (14)	591 (13)	580 (10)	582 (15)
Epoch 3	561 (12)	580 (12)	573 (10)	559 (12)
Epoch 4	589 (11)	582 (9)	575 (9)	583 (7)

Table 1.2. Mean of Accuracy and Standard Error of the Mean (in percentage) as a Function of Epoch, Cue Color, and Cue Validity in Experiment 1.

	Predicted color		Non-predicted color	
	Valid	Invalid	Valid	Invalid
Epoch 1	90.3 (2.4)	88.5 (2.4)	92 (1.8)	90.6 (2.4)
Epoch 2	84.7 (3.0)	89.6 (2.5)	89.9 (2.1)	86.5 (2.8)
Epoch 3	91 (2.2)	90.6 (1.7)	88.9 (1.9)	90.6 (2.0)
Epoch 4	86.5 (2.5)	90.6 (1.8)	90.3 (2.3)	88.5 (2.2)

Discussion

The current experiment demonstrated the non-spatial context-driven search only after the mismatch trials. Specifically, after the mismatch trials, the shape contexts triggered attentional control setting for colors predicted by the shape contexts. Accordingly, the shape-predicted color cues captured attention more than the non-predicted color cues, showing a larger cueing effect for the predicted than non-predicted color cues. Additionally, consistent with the previous findings (Anderson, 2015; Gozli et al., 2014), the shape context guiding attention to the shape-associated color was found under circumstances (mismatch trials) likely to increase cognitive resources for the shape/color association (epoch 3). Although the effect after the mismatch trials demonstrates that the association was learned before the mismatch trials, the association was not used to guide attention until the mismatch trials disrupted the association.

Experiment 2

Experiment 2 aimed to replicate the results of Experiment 1. It was important to see if the use of the epoch size of 48 trials would be effective in a new experiment given that the epoch size was determined based on visual inspection of the pattern of results in Experiment 1. The exploratory attention and conflict-driven cognitive control are known to not be long lasting (Rey-Mermet & Meier, 2017; Kaye & Pearce, 1984), and Experiment 1 suggests that the effect is gone in as short as 48 trials. The purpose of Experiment 2 was to test if these findings of Experiment 1 would generalize and be replicated when using a different type of mismatch trials. Another typical way of violating regularities in the incidental associative learning is omitting an expected event (e.g., Den Ouden, Friston, Daw, McIntosh, & Stephan, 2008). Experiment 1 swapped the association on the mismatch trials; therefore, although the association was broken, the expected color (red or green) was seen in the search display. In contrast, on the two mismatch trials in Experiment 2, the target and distractor letters were gray (see Figure 1-4). Like the mismatch trials of Experiment 1, the new type of mismatch trials also conflicted with the match trials, and therefore would likely increase cognitive resources for the shape/color association by inducing exploratory attention and conflict-driven cognitive control. Therefore, we predicted that the pattern of results as found in Experiment 1 would be replicated.

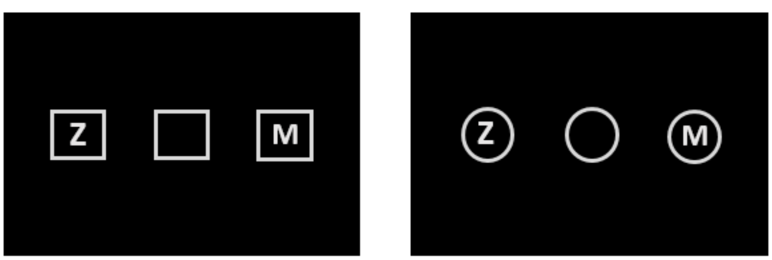


Figure 1.4**.** Examples of gray mismatch trials used in Experiment 2.

Method

Participants. Twenty-four undergraduate students participated for course credit (17 females, average age = 19.33 years, SD = 2.81). All had normal or corrected-to-normal vision.

Apparatus, stimuli, procedure, and design. Experiment 2 was the same as Experiment 1 except for the two mismatch trials where the color of the target and distractor letters was gray (Figure 1-4).

Results

Overall 13.29% of trials were excluded from analysis: trials where RT was shorter than 125 ms (0.03%) or longer than 1000 ms (5.20%) and trials where an incorrect response was made (8.06%).

RT. In epoch 1, the main effects of cue color and validity were not significant, $F(1, 23) = .60$, $p = .45$, $\eta_p^2 = .03$, and $F(1, 23) = 3.12$, $p = .09$, $\eta_p^2 = .12$, respectively. The interaction between cue color and validity was also not significant, $F(1, 23) < .01$, $p = .97$, $\eta_p^2 < .01$. In epoch 2, the main effects of cue color and validity were not significant, $F(1, 23) = .16$, $p = .70$, $\eta_p^2 = .01$, and $F(1, 23) = 3.87$, $p = .06$, $\eta_p^2 = .14$, respectively. The interaction between cue color and validity was also not significant, $F(1, 23) < .01$, $p = .97$, $\eta_p^2 < .01$. In epoch 3, the main effects of cue color and validity were not significant, $F(1, 23) = 1.00$, $p = .33$, $\eta_p^2 = .04$, and $F(1, 23) = .18$, $p = .67$, $\eta_p^2 = .01$, respectively. However, the interaction between cue color and validity was significant, $F(1, 23) = 6.86$, $p = .015$, $\eta_p^2 = .23$, and was due to a larger validity effect for the predicted than non-predicted color cue (the non-spatial context-driven search effect). Post hoc

tests further revealed that the predicted color cue produced a significant validity effect [20 ms; $t(23) = 2.19$, $p = .04$] while the non-predicted color cue did not [-15 ms; $t(23) = -1.63$, $p = .12$]. In epoch 4, the main effects of cue color and validity were not significant, $F(1, 23) = .04$, $p = .84$, $\eta_p^2 < .01$, and $F(1, 23) < .01$, $p = .97$, $\eta_p^2 < .01$, respectively. The interaction between cue color and validity was also not significant, $F(1, 23) = .12$, $p = .73$, $\eta_p^2 < .01$. The cue validity effect (invalid RTs – valid RTs) for each type of cue and each epoch is reported in Figure 1-5 (see Table 1-3 for invalid and valid RTs).

To further confirm the lack of non-spatial context-driven search effect before the mismatch trials, new ANOVAs (see Appendix B) on cue color and cue validity were conducted for RT averaged across every 80 trials (1-80, 81-160, 161-240, 241-320, 321-400, 401-480, 481-560, 561-640, 641-720, and 721-800 trials; see Figure 1-5). The 7th interval (481-560 trials) of 10 intervals showed a significant interaction between cue color and cue validity, $F(1, 23) = 6.03$, $p = .02$, $\eta_p^2 = .21$, however, the other nine intervals did not, indicating no reliable effect.

Accuracy. None of the interactions or main effects of cue color and validity were significant in any of the epochs. In epoch 1, the main effects of cue color and validity were not significant, $F(1, 23) = .01$, $p = .92$, $\eta_p^2 < .01$, and $F(1, 23) =.10$, $p = .74$, $\eta_p^2 < .01$, respectively. The interaction between cue color and validity was also not significant, $F(1, 23) = .01$, $p = .90$, $\eta_p^2 < .01$. In epoch 2, the main effects of cue color and validity were not significant, $F(1, 23) = .30$, $p = .58$, $\eta_p^2 = .01$, and $F(1, 23) =1.70$, $p = .20$, $\eta_p^2 = .07$, respectively. The interaction was not significant, $F(1, 23) = 3.68$, $p = .07$, $\eta_p^2 = .13$. In epoch 3, the main effects of cue color and validity were not significant, $F(1, 23) = .50$, $p = .48$, $\eta_p^2 =.02$, and $F(1, 23) =.03$, $p = .85$, η_p^2

< .01, respectively. The interaction was not significant, $F(1, 23) = .65$, $p = .42$, $\eta_p^2 = .03$. Furthermore, Bayes Factor (BF_{01}) = 3.05 suggested that the null was 3.05 times more likely than the interaction, supporting the non-spatial context-driven search effect in RT was not due to speed-accuracy tradeoff. In epoch 4, the main effects of cue color and validity were not significant, $F(1, 23) = .81$, $p = .37$, $\eta_p^2 = .03$, and $F(1, 23) = .80$, $p = .38$, $\eta_p^2 = .03$, respectively. The interaction was not significant, $F(1, 23) = .02$, $p = .88$, $\eta_p^2 < .01$, (see Table 1-4).

Awareness Question. No participant reported noticing the association between the context and color of the target.

Discussion

In Experiment 2 we used a different type of mismatch trial from Experiment 1 but the same epoch size as Experiment 1. Therefore, Experiment 2 generalized and replicated the findings of Experiment 1: the non-spatial context-driven effect occurred only immediately after the mismatch trials (epoch 3). Together, Experiments 1 and 2 demonstrate that contexts can trigger attentional control settings for a color predicted by a given context. In addition, like the previous studies (Anderson, 2015; Gozli et al., 2014), expression of the non-spatial context-driven search needed additional cognitive resources. Specifically, the addition of the mismatch trials increases allocation of cognitive resources (i.e., attention and working memory), temporarily allowing the use of the learned association to guide attention. Without this increase in resources, even though the association has been present for hundreds of trials, the association is not used to guide attention.

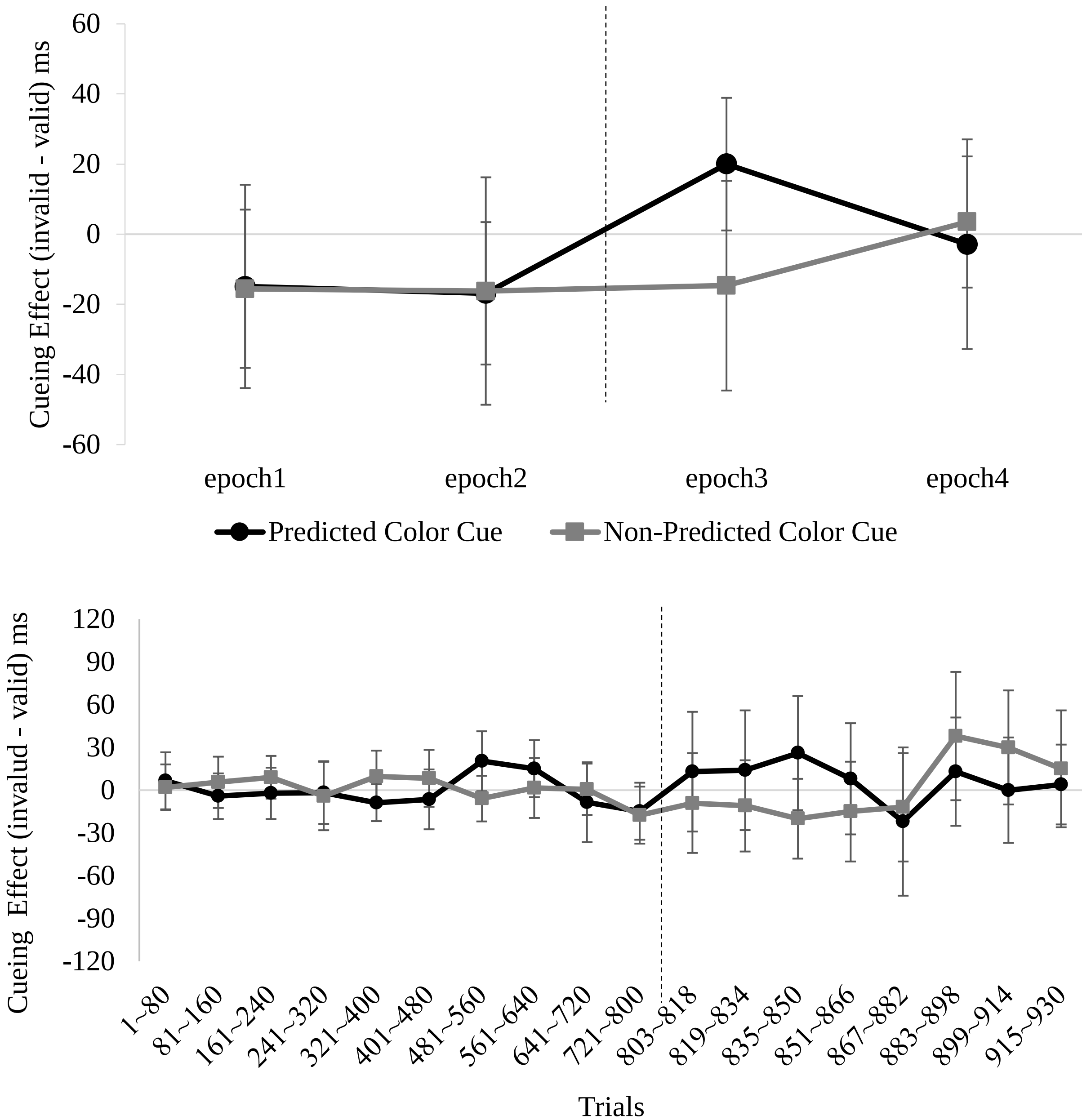


Figure 1.5**.** Results of Experiment 2.

In the top graph, each of epochs 1-4 includes 48 trials and across the following range of trials: 705-752, 753-800, 803-850, and 851-898, respectively. The bottom graph is the data in bins of 80 trials until the mismatch trials and then bins of 16 trials after the mismatch trials. The mismatch trials occurred between epochs 2 and 3, on trials 801 and 802 (see dashed black vertical line). Error bars represent 95% confidence intervals.

Table 1.3. Mean Response times and Standard Error of the Mean (in Milliseconds) as a Function of Epoch, Cue Color, and Cue Validity in Experiment 2.

	Predicted color		Non-predicted color	
	Valid	Invalid	Valid	Invalid
Epoch 1	587 (20)	572 (15)	580 (13)	564 (14)
Epoch 2	577 (15)	560 (16)	580 (16)	564 (18)
Epoch 3	541 (12)	561 (11)	552 (12)	537 (12)
Epoch 4	554 (14)	551 (13)	550 (11)	553 (12)

Table 1.4. Mean of Accuracy and Standard Error of the Mean (in percentage) as a Function of Epoch, Cue Color, and Cue Validity in Experiment 2.

	Predicted color		Non-predicted color	
	Valid	Invalid	Valid	Invalid
Epoch 1	91 (2.3)	91.3 (1.7)	91 (1.9)	91.7 (1.8)
Epoch 2	92.7 (1.8)	91.3 (1.9)	88.5 (2.1)	93.8 (1.7)
Epoch 3	92 (1.8)	91.3 (2.3)	92 (1.5)	93.4 (1.9)
Epoch 4	89.9 (1.9)	90.6 (2.0)	91.3 (1.8)	92.4 (1.4)

Experiment 3

In Experiments 1 and 2, a break was given just before the mismatch trials. Experiment 3 verified if the non-spatial context-driven search was influenced by the break rather than the mismatch trials. Thus, Experiment 3 was identical to Experiment 2 except for the absence of the break. Furthermore, the sample size for Experiments 1 and 2 was based on previous research, but the effect found in the current research is smaller than those found in previous research. Therefore, we used the effect size from Experiment 2 to estimate the sample size needed in Experiment 3. In addition, in Experiments 1 and 2, we were operating with an apriori hypothesis that the effect would be found only in epoch 3. However, a more conservative approach is needed to increase confidence in the validity of this effect. Therefore, in Experiment 3 we used a Bonferroni correction (alpha = 0.0125) for multiple analyses across 4 epochs.

Method

Participants. Forty-four undergraduate students participated for course credit (33 females, average age = 18.9 years, SD = 1.45). The sample size was based on the effect size (η_p^2 = .23) of the cue-validity difference between colors in epoch 3 of Experiment 2. G power (a power of 0.80, an alpha of 0.0125 adjusted by Bonferroni correction, the effect size of η_p^2 = .23) indicated the minimum sample size, 42. All had normal or corrected-to-normal vision.

Apparatus, stimuli, procedure, and design. Experiment 3 is identical to Experiment 2 except that the break before the mismatch trials was removed.

Results

Overall, 10.39% of trials were excluded from analysis: trials where RT was shorter than 125 ms (0.08%) or longer than 1000 ms (3.39%) and trials where an incorrect response was made (6.92%).

RT. In epoch 1, the main effects of cue color and validity and the interaction were not significant, $F(1, 43) = .07$, $p = .80$, η_p^2 <.01, $F(1, 43) =.11$, $p = .74$, η_p^2 <.01, and $F(1, 43) = .54$, $p = .46$, η_p^2 = .01, respectively. In epoch 2, the main effects of cue color and validity and the interaction were not significant, $F(1, 43) = .01$, $p = .92$, $\eta_p^2 < .01$, $F(1, 43) =1.16$, $p = .29$, η_p^2 =.03, and $F(1, 43) = 1.04$, $p = .31$, η_p^2 = .02, respectively. In epoch 3, the main effects of cue color and validity were not significant, $F(1, 43) = .25$, $p = .62$, η_p^2 <.01, and $F(1, 43) =.09$, p = .75, $\eta_p^2 < .01$, respectively. Critically, the interaction between cue color and validity was

significant, $F(1, 43) = 8.45$, $p = .006$, $\eta_p^2 = .16$, indicating the non-spatial context-driven search effect. Post hoc tests further revealed that the predicted color cue produced a marginally significant validity effect [11 ms; $t(43) = 1.64$, $p = .10$] and significant for the non-predicted color cue [-14 ms; $t(43) = -2.09$, $p = .04$]. As in Experiments 1 and 2, the interaction (non-spatial context-driven search effect) of epoch 3 appears to be the result of the trend of both the validity effect of the predicted color cue and the reversed validity effect of the non-predicted cue. This appears to be due to the contexts predicting both target color, which was the same color as the predicted color cue, and distractor color, which was the same color as the non-predicted color cue, leading to facilitating the predicted target color (the predicted color cue) and suppressing the predicted distractor color (the non-predicted color cue). In epoch 4, the main effects of cue color and validity and the interaction were not significant, $F(1, 43) = .02$, $p = .89$, $\eta_p^2 < .01$, $F(1, 43) = .31$, $p = .58$, $\eta_p^2 < .01$, and $F(1, 43) = .23$, $p = .63$, $\eta_p^2 < .01$. The cue validity effect (invalid RTs – valid RTs) for each type of cue and each epoch is reported in Figure 1-6 (see Table 1-5 for invalid and valid RTs).

New ANOVAs (see Appendix C) on cue color and cue validity were conducted for RT averaged across every 80 trials before the mismatch trials (1-80, 81-160, 161-240, 241-320, 321-400, 401-480, 481-560, 561-640, 641-720, and 721-800 trials; see Figure 1-6). No significant interactions between cue color and cue validity (no non-spatial context-driven search effect) were found in any of the epochs (all *ps* > .08).

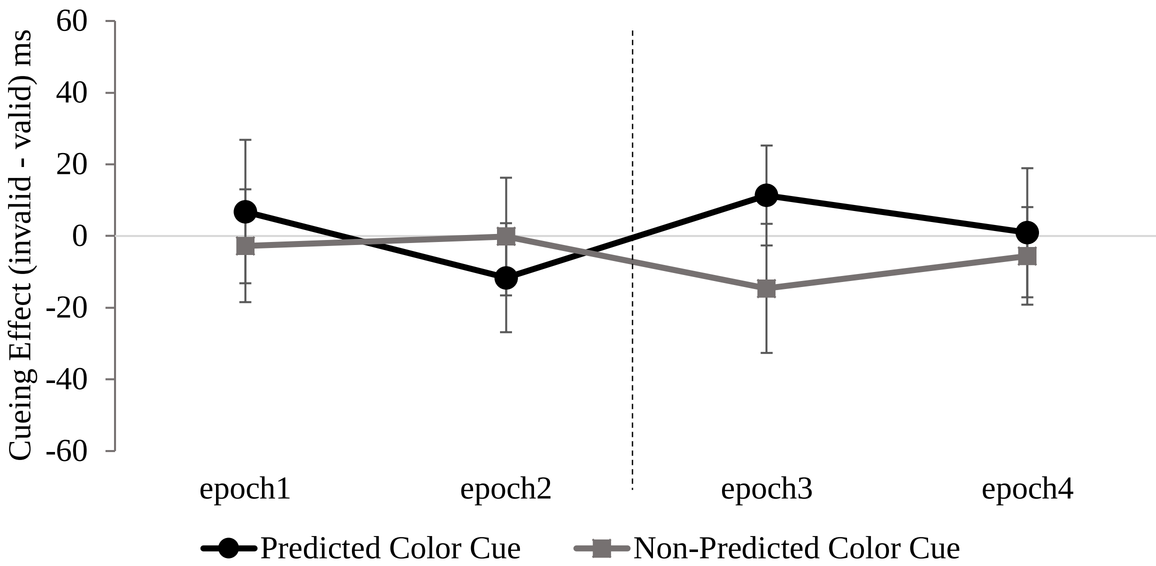
Accuracy. No interactions between color and validity were significant in any of the epochs. In epoch 1, the main effects of cue color and validity were not significant, $F(1, 43) = 1.65$, $p = .20$, $\eta_p^2 = .03$, and $F(1, 43) = 5.53$, $p = .02$, $\eta_p^2 = .11$, respectively. The interaction

between cue color and validity was also not significant, $F(1, 43) = .25$, $p = .61$, $\eta_p^2 < .01$. In epoch 2, the main effects of cue color and validity were not significant, $F(1, 43) = 2.0$, $p = .16$, $\eta_p^2 = .04$, and $F(1, 43) =.63$, $p = .43$, $\eta_p^2 =.01$, respectively. The interaction between cue color and validity was also not significant, $F(1, 43) = 1.09$, $p = .30$, $\eta_p^2 = .03$. In epoch 3, the main effect of cue color was not significant and the main effect of validity significant, $F(1, 43) = 2.86$, $p = .09$, $\eta_p^2 = .06$, and $F(1, 43) = 8.76$, $p = .005$, $\eta_p^2 = .16$, respectively. Critically, no interaction was observed, $F(1, 43) < .01$, $p = .93$, $\eta_p^2 < .001$. Additionally, Bayes Factor (BF_{01}) = 4.5 indicated that the null was 4.5 times more likely than the interaction, supporting no evidence of speed-accuracy trade-off. In epoch 4, the main effects of cue color and validity were not significant, $F(1, 43) = .19$, $p = .66$, $\eta_p^2 < .01$, and $F(1, 43) = .31$, $p = .58$, $\eta_p^2 < .01$, respectively. The interaction between cue color and validity was also not significant, $F(1, 43) < .01$, $p = .93$, $\eta_p^2 < .001$ (see Table 1-6).

Awareness Question. No participant reported noticing the association between the context and color of the target.

Discussion

The current experiment removed the break and replicated the results of Experiments 1 and 2: the non-spatial context-driven search was found only in epoch 3. Accordingly, the finding of Experiment 3 suggests that the non-spatial context-driven search was due to the mismatch trials rather than the break.



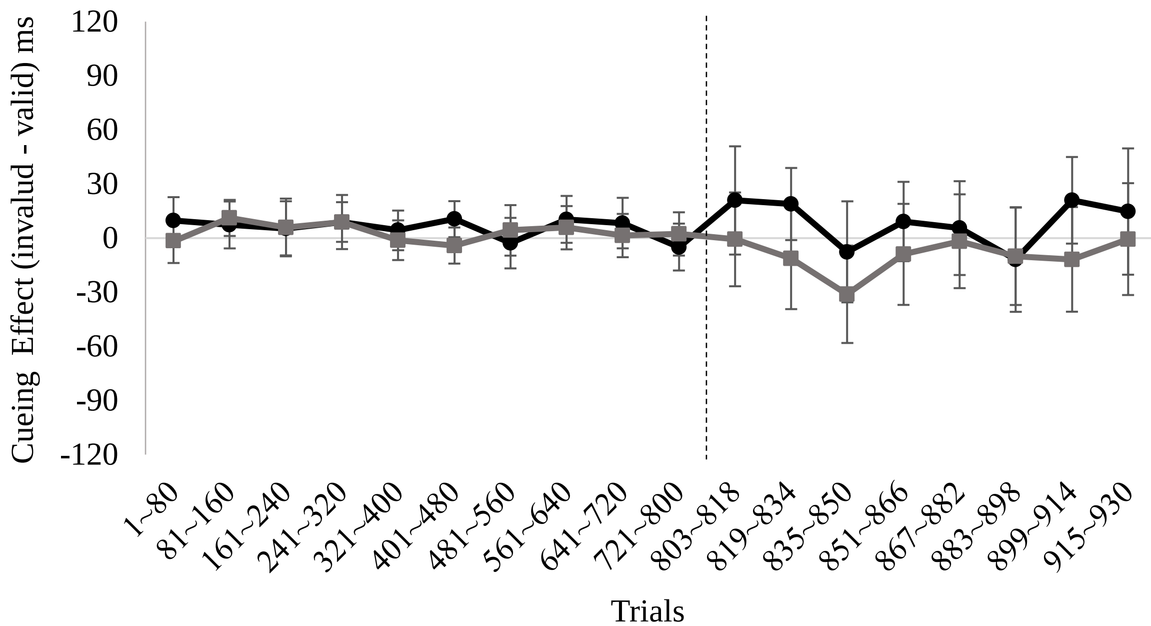


Figure 1.6**.** Results of Experiment 3.

In the top graph, each of epochs 1-4 includes 48 trials and across the following range of trials: 705-752, 753-800, 803-850, and 851-898, respectively. The bottom graph is the data in bins of 80 trials until the mismatch trials and then bins of 16 trials after the mismatch trials. The mismatch trials occurred between epochs 2 and 3, on trials 801 and 802 (see dashed black vertical line). Error bars represent 95% confidence intervals.

Table 1.5. Mean Response times and Standard Error of the Mean (in Milliseconds) as a Function of Epoch, Cue Color, and Cue Validity in Experiment 3.

	Predicted color		Non-predicted color	
	Valid	Invalid	Valid	Invalid
Epoch 1	583 (8)	590 (10)	590 (9)	587 (10)
Epoch 2	586 (9)	575 (8)	580 (6)	580 (9)
Epoch 3	553 (7)	565 (7)	569 (6)	555 (8)
Epoch 4	567 (9)	568 (7)	569 (7)	564 (9)

Table 1.6. Mean of Accuracy and Standard Error of the Mean (in percentage) as a Function of Epoch, Cue Color, and Cue Validity in Experiment 3.

	Predicted color		Non-predicted color	
	Valid	Invalid	Valid	Invalid
Epoch 1	89.2 (1.8)	92.8 (1.3)	91.3 (1.5)	93.9 (1.2)
Epoch 2	91.7 (1.5)	91.9 (1.2)	94.1 (1.0)	92.2 (1.5)
Epoch 3	93.6 (1.0)	96.4 (.09)	91.9 (1.5)	94.9 (1.0)
Epoch 4	93.4 (1.1)	92.6 (1.4)	93.8 (1.3)	93.2 (1.3)

General Discussion

The primary finding of the current study, replicated across three experiments, is that shape contexts can trigger attentional control settings for a target color predicted by the contexts (non-spatial context-driven search). Despite extensive evidence showing attentional control settings for non-spatial features such as color and shape in visual search (see Lamy & Kristjánsson, 2013; Maunsell & Treue, 2006 for a review), the amount of evidence for non-spatial context-driven search (Anderson, 2015; Gozli et al., 2014) is low compared to evidence for spatial context-driven search (Brockmole et al., 2006; Chun, 2000; Chun & Jiang, 1998, 2003; Jiang & Wagner, 2004; Jiang et al., 2013; Olson & Chun, 2002; Rosenbaum & Jiang, 2013). This study adds to evidence for non-spatial context-driven search and demonstrates conditions under which non-spatial context-driven search may or may not be evident.

Specifically, the non-spatial context-driven search occurred only after a transient violation in a learned association between a shape context and a target color. This suggests that context-driven search requires sufficient cognitive resources for expression of contexts guiding attention (Manginelli et al., 2013; Jiang & Leung, 2005).

The lack of a non-spatial context-driven search effect prior to the mismatch trials and the presence of an effect after the mismatch trials suggests that the expression of the context-driven cueing effect will be absent if cognitive resources are not sufficiently allocated to the learned association. Two possible mechanisms by which the mismatch trials can increase cognitive resources are exploratory attention and conflict-driven cognitive control. In associative learning, when previously learned associations are violated, exploratory attention increases attentional resources to the uncertain stimuli to be resolved (Easdale et al., 2019; Griffiths et al., 2011; Hall & Pearce, 1982; Wills et al., 2007; Wilson et al., 1992). Furthermore, detection of cognitive conflict triggers an up-regulation in cognitive control by allocating cognitive resources to the task-relevant information (Egner & Hirsch, 2005). The shape context predicted the color of the targets. Therefore, an up-regulation in cognitive control would lead to an increase in cognitive resources for the shape/color associations. Although the shape contexts could not trigger attentional control settings for the shape-predicted color before the mismatch trials due to insufficient cognitive resources for the shape/color association, the mismatch trials allow the necessary cognitive resources for shape contexts to trigger attentional control for the associated color.

The non-spatial context-driven search by the aid of the mismatch trials increasing cognitive resources for the shape/color association is consistent with previous findings. In previous studies showing non-spatial context-driven attentional sets, a methodological factor

existed that increased allocation of cognitive resources to the task. Anderson (2015) found the shape contexts triggering attentional control setting for color when the shape/color association involved reward learning. Reward is a critical factor enhancing associative learning (Hyman et al., 2006). Gozli et al. (2014) found the non-spatial context-driven search when a single object contained both the shape and color features so that the shape/color association received attentional benefits. However, they did not find the non-spatial context-driven search without the conjunctive presentation because such the attentional benefits to the shape/color association are removed. In line with this, in the current study, without the aid of the mismatch trials, the non-spatial context-driven search was not found (prior to the mismatch trials). Therefore, the use of learned shape/color associations to guide attention appears to require a boost in cognitive resources.

Although the spatial context-driven search was commonly found without methodological factors increasing cognitive resources for the association of spatial features (Brockmole et al., 2006; Chun, 2000; Chun & Jiang, 1998, 2003; Jiang & Wagner, 2004; Jiang, Sigstad, & Swallow, 2013; Olson & Chun, 2002; Rosenbaum & Jiang, 2013; see Goujon et al., 2015 for review), it was interrupted when there were obstructers preventing the spatial association from receiving cognitive resources (Manginelli et al., 2013; Jiang & Leung, 2005). The spatial context-driven search did not occur when contexts received few attentional resources (Jiang & Leung, 2005) or when working memory was used for a different task (Manginelli et al., 2013). Taken together with the non-spatial context-driven search requiring additional cognitive resources, the spatial context-driven search not requiring the additional cognitive resources but being interrupted by the obstructers suggests that cognitive resources modulate the context-driven search and supports that the context-driven search requires more cognitive resources for

the non-spatial than spatial context-driven search. A different allocation of cognitive resources required for the non-spatial and spatial context-driven search might in part account for rare evidence of the non-spatial compared to spatial context-driven search despite the ability to establish attentional control settings for non-spatial features such as color and shape (Lamy & Kristjánsson, 2013; Maunsell & Treue, 2006).

The requirement of more cognitive resources for the non-spatial than spatial associative learning is also consistent with the finding that memory for spatial information is used more than non-spatial information of distracters to guide attention during search (Beck, Peterson, & Vomela, 2006). For example, when locations of the previously attended distracters were changed, search was interrupted. However, when identity (color and shape) of attended distractors was changed, search was not interrupted, suggesting that spatial rather than non-spatial information was used to guide attention. In other words, to use non-spatial information during search, additional task situations by which more cognitive resources are allocated to the non-spatial information may be needed. In the non-spatial context-driven search, the situations were made via methodological factors that boost available cognitive resources.

The non-spatial context-driven search in the present study appears to be the result of the trend of both the validity effect of the predicted color cue and the reversed validity effect of the non-predicted color cue. This pattern is not surprising given the fact that the contexts predicted both target color (the same color as the predicted color cue) and distractor color (the same color as the non-predicted color cue). Known target-features can be facilitated, increasing attention to the targets (Desimone & Duncan, 1995; Wolfe, 1994). In addition, known non-target-features can be suppressed, preventing attention to the non-targets (Arita, Carlisle, & Woodman, 2012; Geng, DiQuattro, & Helm, 2017). These general attentional abilities of the facilitation (for

selection) and suppression (for filtering out) were found in a previous context-driven search study (Ogawa, Takeda, & Kumada, 2007) where the contexts triggered the attentional facilitation of the context-predicted target information and attentional suppression of the context-predicted distractor information. In the pre-cueing paradigm, the attentional facilitation and suppression are indicated by the validity and reversed validity effects, respectively (e.g., Belopolsky, Schreij, & Theeuwes, 2010; Kerzel, 2019). Thus, the trend of the validity effect of the predicted color cue and the reversed validity effect of the non-predicted color cue in the present study would reflect the contexts predicting target color and distractor color.

The use of the shape/color associations *immediately after* the mismatch trials implies that the associations were already learned before the mismatch trials. That is, the associative learning occurred automatically, but the use of this learned information did not. This is in line with the previous research (Manginelli et al., 2013; Jiang & Leung, 2005) where cognitive resources (working memory in Manginelli et al., 2013, attention in Jiang & Leung, 2005) were needed for the use (expression) of the learned associations to guide attention, whereas learning the associations did not depend on cognitive resources.

In a close inspection of the first 16 trials after the mismatch trials, the non-spatial context-driven search appears to be slightly delayed in Experiment 1 compared to Experiments 2 and 3. One possibility is that this is due simply to noise in the data given that there are only 16 trials in each epoch. Another possibility is that this difference is due to the use of different types of mismatch trials. The mismatch trials in Experiment 1 were the reverse of the match trials, whereas in Experiments 2 and 3 color was removed in the mismatch trials. Therefore, in Experiment 1, a reversed non-spatial context-driven search effect (a non-predicted color cue capturing attention more than a predicted color cue) might be slightly induced by the two

mismatch trials having the opposite color-shape associations. This might have led to the slight delay in Experiment 1 compared to Experiments 2 and 3.

In conclusion, the present study demonstrated that associations between shape and color can be learned, and then the shape contexts can guide attention to the shape-predicted color. However, this non-spatial context-driven effect may fail to be used to guide attention without a boost in cognitive resources (Gozli et al., 2014) that does not appear to be necessary for spatial context-driven search (Chun & Jiang, 1998). This is also in line with research other than context-driven search showing that spatial information is processed more automatically during search than non-spatial information search (Beck et al., 2006).

Chapter 2: Reference Dependence in Value-Driven Attention

This chapter previously appeared as [Kim and Beck (2020). Impact of relative and absolute values on selective attention. Psychonomic Bulletin & Review]. It is reprinted by permission of Sunghyun Kim—see the permission letter (Appendix E) for proper acknowledgment phrase.

Impacts of Relative and Absolute Values on Selective Attention

Only a limited amount of information can be attended at a given time (Broadbent, 1958). A growing body of evidence shows that the value of an object can influence attentional allocation: value-driven attentional capture (Anderson, Laurent, & Yantis, 2011; Chelazzi, Perlato, Santandrea, & Della Libera, 2013; Lee & Shomstein, 2014). However, there are two types of value, relative value and absolute value. The relative value of an object is dependent on the values of the other available objects in the same context (e.g., *higher* or *lower*), whereas the absolute value of an object is not influenced by the values of other available objects (e.g., *50 points*). Critically, both types of values are represented separately and simultaneously in the brain (Grabenhorst & Rolls, 2009). However, this does not necessarily mean that the relative and absolute values equally influence human behaviors (e.g., Kahneman & Tversky, 1979). Thus, the present study explored whether the relative and/or absolute value associated with an object determines if the object will attract attention.

Prospect theory (Kahneman & Tversky, 1979) suggests that relative rather than absolute value influences behaviors in later cognitive stages such as judgement and decision making (the reference dependence aspect of prospect theory). According to prospect theory, the value of an object is determined by a reference point for the object. For example, when it is possible to gain either 1 or 10 dollars, receiving 10 dollars will give rise to satisfaction, but when it is possible to gain either 10 or 20 dollars, receiving 10 dollars will lead to disappointment. In this case, the reference point of either 1 dollar or 20 dollars determines the amount of satisfaction in receiving 10 dollars. The critical role of the relative value on judgement and decision making has been extensively demonstrated in behavioral economics (for a review, Barberis, 2013).

It is, however, unclear whether relative rather than absolute value (the reference dependence aspect of prospect theory) affects earlier cognitive stages, such as selective attention, because research on prospect theory has been focused on the later cognitive stages like judgement and decision making. Another aspect of prospect theory (the weighting function of prospect theory) has been shown to extend to earlier cognitive stages (Vincent, 2011). Specifically, during visual search, the probability of a search target appearing at a particular location was overweighted when the probability was low and underweighted when it was high. This pattern is consistent with the weighting function of prospect theory (Kahneman & Tversky, 1979), alluding to the extendibility of prospect theory to selective attention. Thus, the current research investigates the reference dependence aspect of prospect theory in selective attention. This step is critical to determining the applicability of prospect theory to selective attention because reference dependence is considered the key premise of prospect theory (Bendor, 2004).

The current study tests the applicability of the reference dependence aspect of prospect theory to selective attention by modifying the value-driven attentional capture paradigm to independently manipulate the relative and absolute values. Previous studies on value-driven attentional capture could not determine whether valuable stimuli capturing attention was due to the relative or absolute value of the stimuli because the valuable stimuli were not only relatively but also absolutely more valuable (e.g., Anderson, Laurent, & Yantis, 2011; Bucker & Theeuwes, 2017; Le Pelley, Pearson, Porter, Yee, & Luque, 2019; MacLean & Giesbrecht, 2015; Mine & Saiki, 2015; Roper, Vecera, & Vaidya, 2014). Therefore, we needed to modify the typical methodology used in previous value-driven attentional capture literature such that the absolute value and the relative value could be independently manipulated.

In a typical value-driven attentional capture study, associations of value for stimuli are learned during a training phase and then a test phase reveals that stimuli previously associated with a higher reward value receive attentional priority compared to stimuli previously associated with a lower reward value (Anderson et al., 2011; Bucker & Theeuwes, 2017; Mine & Saiki, 2015). For instance, the Anderson et al. (2011) study included a training phase in which the associative learning between color and reward value occurred. Participants searched for red and green circles amongst different color circles, and one of these target colors was presented on each trial. Critically, in the training phase, higher rewards were given more often when the target was red (5 cents for 80% of the trials and 1 cent for 20% of the trials) compared to when it was green (1 cent for 80% of the trials and 5 cents for 20% of the trials). Accordingly, the absolute value was higher for red than for green. In the test phase, the high valued color captured attention more than the low valued color. The target defining feature during the test phase was a unique shape instead of color (a white circle among white diamonds or a white diamond among white circles). Critically, on some trials, one of the distractors was red (high valued color) or green (low valued color) equally often: color singleton distractor. Although there was no benefit in attending to the color singleton distractors (i.e., color was task-irrelevant and reward was no longer given), responses were slower when the singleton distractor was the high valued color (red) than when it was the low valued color (green). This finding led the authors to conclude that stimuli previously associated with a higher value captured attention more (Anderson et al., 2011).

This typical methodology (e.g., Anderson et al., 2011) of value-driven attentional capture cannot reveal whether the mechanism by which value modulates selective attention is based on relative or absolute value. This is because the high reward associated color had a higher absolute

and a higher relative value than the low reward associated color in the training phase. Specifically, both the higher and lower valued colors were target colors in the same context (the training phase): one of the target colors was randomly chosen to be presented on each trial in the training phase. Therefore, both target colors were always task relevant throughout the training phase, allowing each color to become a reference point for the other to compare their reward values. In line with this, Anderson (2016) mentioned that the relative and absolute values had not been independently manipulated in a single experiment.

Anderson (2016), however, stated that relative rather than absolute value seemed to influence value-driven attentional capture. The idea remained unsolved because it is obtained from suggestive evidence across multiple studies. Accordingly, the present study directly tested the impacts of the relative and absolute values on value-driven attentional capture through the independent manipulation of relative and absolute values in a single experiment.

To independently manipulate relative and absolute values, the present experiments adapted reference dependence (Kahneman & Tversky, 1979) into the classic value-driven attentional capture paradigm (Anderson et al., 2011). In the training phase, there were two separate contexts so that each of the test target colors (red and green) that were used as value-associated distractor colors in the test phase had a different reference target color (yellow, blue) during the training phase. Accordingly, the use of separate contexts permitted the independent manipulation of relative and absolute values. Experiment 1 examined the impact of the relative value while controlling the absolute value. Experiment 2 examined the impact of the absolute value while controlling the relative value.

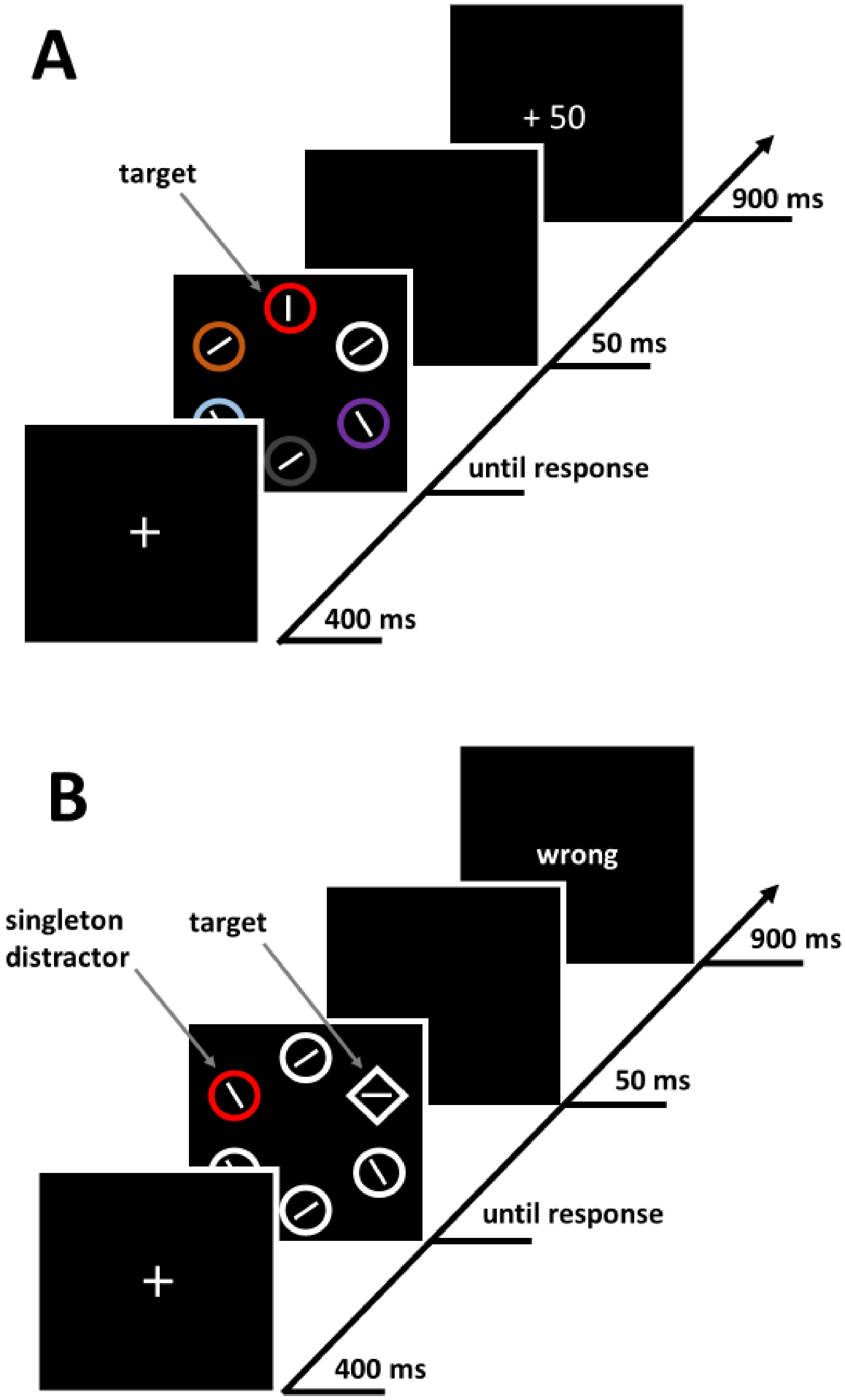


Figure 2.1**.** Sequence of trial events of the training phase (A) and the test phase (B) in Experiments 1 and 2.

Experiment 1

To explore the impact of relative value on selective attention, on the basis of the Anderson et al.'s (2011) paradigm, we made the absolute reward values of red and green the same and the relative reward values different by providing the associative learning of value for red and green in separate context blocks (see Table 2-1). For example, in blocks 1, 3, and 5 of the training phase, target colors were red and yellow, and red targets were more likely to give a higher reward than yellow targets. In blocks 2, 4, and 6, target colors were green and blue, and green targets were more likely to give a lower reward than blue targets. Accordingly, while the absolute value of red and green was the same, the relative value was higher for red and lower for green due to their different reference points (yellow and blue associated values respectively). In the test phase, as in Anderson et al. (2011), the target was a unique shape, and on some trials either a red or green singleton distractor was presented (see Figure 2-1). If the relative value influences selective attention, search will be slower when the target appears with the high than when it appears with the low relative value color distractor.

Method

Participants. Fifty-six undergraduate students with normal or corrected-to normal vision participated for course credit. The sample size was determined from value-driven effect sizes in Anderson et al. (2011). The critical analysis to assess value-driven attentional capture was a comparison between the high and low value color distractors in the test phase. G power (power = 0.95, alpha = 0.05, and Cohen's D = 0.81) showed that at least 19 participants were necessary. However, the number of training trials (504 trials) for each color in Anderson et al. was around three times of those (180 trials) in the current study, so we aimed for three times the sample size.

Apparatus and Stimuli. Stimuli were presented on a 20-inch monitor. The distance between the participants and the monitor was approximately 60 cm but was not constrained.

In the training phase, each trial consisted of fixation, search, blank, and feedback displays (see Figure 2-1). The background of the screen was black for all displays. In the fixation display, a white cross bar was presented in the center of the screen. In the search display, six circles (1.4° diameter each) were presented around an invisible circle (5° radius). Inside a target object, a horizontal or vertical white line was presented, and inside each distractor object, a white line tilted 45° to the left or right was presented. One of the six circles was a target color (yellow, red, green, or blue) and the others were distractor colors (orange, purple, aqua, white, and gray). In the search display of the test phase (see Figure 2-1), the search target was unique shape: a circle among diamonds or a diamond among circles.

Design. The experiment consisted of 720 training trials followed by 384 test trials (see Table 2-1). The relative value (high, low) of the two test colors (red and green) was manipulated within three alternating blocks of the training phase. Correct responses earned 50 points on 90% of trials and 1 point on 10% of trials for the test target colors (red and green). For the reference target colors, correct response earned 100 points on 90% of trails and 1 point on 10% of trials for one of the reference target colors (blue and yellow), and 1 point on 90% of trials and 50 points on 10% of trials for the other. The test target color that was paired with the reference target color receiving 100 points (90%) and 1 point (10%) in the training blocks was the *low* relative value target color. The test target color paired with the reference target color receiving 1 point (90%) and 50 points (10%) in the training blocks was the *high* relative value target color. Within each block, each of the two target colors (one test target color and one reference target color) were presented on 50% of trials.

The test target colors (red or green), the reference target colors (yellow or blue), and the block order were fully counterbalanced across the participants. Specifically, in 1, 3, and 5 blocks of training, the target colors were a test target color (either red or green) and a reference target color (either blue or yellow). In 2, 4, and 6 blocks of training, the target colors were the two remaining colors (e.g., if red and yellow in 1, 3, and 5 blocks, then green and blue in 2, 4, and 6 blocks).

Table 2.1: Relative Value of Experiment 1 Training Phase

	Block					
Reward Points	1	2	3	4	5	6
50 (90%) 1 (10%)	Red (high)	Green (low)	Red (high)	Green (low)	Red (high)	Green (low)
1 (90%) 50 (10%)	Yellow		Yellow		Yellow	
100 (90%) 1 (10%)		Blue		Blue		Blue

Note. In this example, target colors are red and yellow in the 1, 3, and 5 context blocks and green and blue in the 2, 4, and 6 context blocks. The absolute value of the red and green is the same (50 points on 90% of trials, 1 point on 10% of trials), whereas the relative value of them is different (red is relatively higher compared to yellow (a reference point of red) and green is relatively lower compared to blue (a reference point of green)). In the test phase, singleton color distractor is red (high relative value in the training) or green (low relative value in the training). The test target colors (red and green), the reference target colors (yellow and blue), and the block order were fully counterbalanced across 56 participants.

Procedure. In the training phase, participants were instructed to find a circle with one of the two target colors and report the orientation of the line inside the circle by pressing the N-key for a horizontal line or M-key for a vertical line as quickly and accurately as possible. On each trial, the fixation display was presented for 400ms, followed by the search display until a response was made. After the response, there was a blank display for 50ms and then a feedback display for 900ms. In the feedback display, earned points (e.g., + 50) were presented when a

correct response was made within 1500ms. For incorrect responses, '+ 0 (wrong)' was presented. For slow responses (over 1500 ms), '+ 0 (too slow)' was presented.

Participants first completed 40 practice trials during the training phase. In the first 20 practice trials, the target colors were the same as the target colors in the 1st, 3rd, and 5th training blocks (e.g., red and yellow). In the second 20 practice trials, the target colors were the same as those of 2nd, 4th, and 6th training blocks (e.g., green and blue). Before each practice, oral and written instructions regarding the target colors were provided. Before each of the six training blocks, written instruction regarding the target colors was provided. Participants were informed before that they would receive points when fast and correct responses were made, and the experiment would finish earlier as they received more points. However, unbeknownst to the participants, earned points did not affect the number of trials in the experiment.

The test phase followed immediately after the training phase, participants were instructed to search for a unique shape (a circle among diamonds or a diamond among circles) and report the orientation of the line in the unique shape; therefore, color was task-irrelevant. Also, they were informed that reward points were not given in the test phase. The timing of each screen and required response was the same as in the training phase, but the search display was replaced with the shape singleton search display (see Figure 2-1). During 20 practice trials, an experimenter checked and confirmed that participants understood the singleton shape detection instructions. Then, 384 randomly ordered test trials were given. On 96 of the 384 trials, one of non-target objects was green. On another 96 trials, one of non-target objects was red. On the remaining 192 trials, all objects were white.

Results

The dependent variable was response time (RT) recorded from the onset of the search display. Only correct responses were included in analyses of RTs (incorrect trials: 4.6% in training phase, 8.6% in test phase). Also, trials in which RT was shorter than 150ms (0% in training phase, 0.1% in test phase) or longer than 1500ms (0.9% in training phase, 5.6% in test phase) were excluded from the analysis. The first three trials of each block in the training phase and of the test phase were also excluded from the analysis to allow some time to change the attentional control settings.

Training phase. RT was not different between when the target was relatively high valued color (mean = 668 ms, standard error = 9 ms) and low valued color (mean = 668 ms, standard error = 10 ms), $t(55) = .01$, $p = .99$.

Test phase. RT was shorter when no color singleton distractor was presented (790 ms) than when the high (866 ms) and low (854 ms) valued color singleton distractors were presented, $ps < .001$. Importantly, RT was slower when the high relative value color distractor was presented than when the low relative value color distractor was presented, $t(55) = 2.28$, $p = .027$, d=.30 (see Figure 2-2), suggesting that the high relative value color distractor captured attention more than the low relative value color distractor. This effect was not due to the speed-accuracy trade-off, given that accuracy was not different between the low (91.48%) and high (91.25%) relative value color distractors, $t(55) = .39$, $p = .69$. This implies that the high relative value color distractor captured attention more than the low relative value color distractor. Accordingly, relative value influenced selective attention.

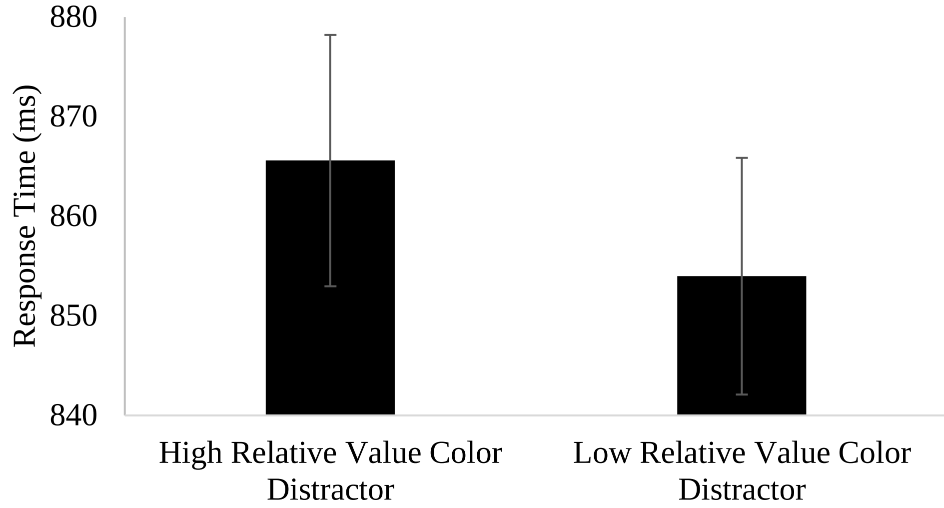


Figure 2.2**.** Mean of response times in the test phase of Experiment 1.
Error bars represent standard error of the mean.

Experiment 2

The purpose of Experiment 2 was to examine if the absolute value influences value-driven attentional capture. Therefore, while the relative value of red (higher) and green (higher) was the same, their absolute value was different (see Table 2-2). If absolute value impacts selective attention, the high absolute value distractor would capture attention more than the low valued distractor in the test phase.

Method

Participants. Fifty-six undergraduate students with normal or corrected-to normal vision participated for course credit.

Apparatus, Stimuli, Design, and Procedure. The apparatus, stimuli, design, and procedure were identical to Experiment 1. The only difference was the reward point allocation during training. In the training phase, one test target color (e.g., red) gave 50 points for 90% of

the trials and 1 point for 10% of the trials and the other test target color (e.g., green) gave 100 points for 90% of the trials and 1 point for 10% of the trials (see Table 2-2). One of the reference targets (e.g., yellow) gave 1 point for 90% of the trials and 50 points for 10% of the trials and the other reference target (e.g., blue) gave 50 points for 90% of the trials and 1 point for 10% of the trials.

Table 2.2: Absolute Value of Experiment 2 Training Phase

	Block					
Reward Points	1	2	3	4	5	6
50 (90%) 1 (10%)	Red (low)		Red (low)		Red (low)	
100 (90%) 1 (10%)		Green (high)		Green (high)		Green (high)
1 (90%) 50 (10%)	Yellow		Yellow		Yellow	
50 (90%) 1 (10%)		Blue		Blue		Blue

Note. In this example, target colors are red and yellow in the 1, 3, and 5 context blocks and green and blue in the 2, 4, and 6 context blocks. The relative value of the red and green is the same, whereas the absolute value of them is different (Red: 50 points on 90% of trials and 1 point on 10% of trials, Green: 100 points on 90% of trials and 1 point on 10% of trials). In the test phase, singleton color distractor is red (low absolute value in the training) or green (high absolute value in the training). The test target colors (red and green), the reference target colors (yellow and blue), and the block order were fully counterbalanced across 56 participants.

Results

The following trials were excluded in the analyses: incorrect trials (4.5% in training phase, 7.3% in test phase), trials with RTs shorter than 150ms (0% in training phase, 0.07% in

test phase) or longer than 1500ms (0.7% in training phase, 4.3% in test phase), and the first three trials of each block in the training phase and the test phase.

Training phase. RT was not different between the high absolute value color target (mean = 676 ms, standard error = 12 ms) and low absolute value color target (mean = 676 ms, standard error = 11 ms), $t(55) = .03$, $p = .97$.

Test phase. As in Experiment 1, RT was shorter when no color singleton distractor was presented (789 ms) than when the high (863 ms) and low (860 ms) valued color singleton distractors were presented, *ps* < .001. Critically, RT was not different between when the singleton distractor was the high absolute value color and the low absolute value color (see Figure 2-3), $t(55) = -.86$, $p = .39$, $d = -.11$, suggesting that the high absolute value color distractor did not capture attention more than the low. The lack of RT difference was not due to the speed-accuracy trade-off, given no difference between the low (92.73%) and high (92.59%) absolute value color distractors, $t(55) = .29$, $p = .77$. Additionally, Bayes Factor (BF_{+0}) = 5.4 (van Doorn et al., 2019) indicated that the prediction of more attentional capture by the high than low absolute value color distractor was 5.4 times less favored than the null. Accordingly, there is no evidence of an impact of absolute value on selective attention.

To directly compare the impacts of the relative and absolute values on the value-driven attentional capture, data between Experiments 1 and 2 were compared. The mixed ANOVA on color (high and low valued color singleton distractor) as a within-subject factor and type of value (relative and absolute) as a between-subjects factor revealed an insignificant main effect of color, $F(1, 110) = 1.43$, $p = .24$, $\eta_p^2 = .01$. Critically, the interaction was significant, $F(1, 110) = 5.30$, *p*

= .02, η_p^2 = .05, supporting a stronger impact of relative than absolute value on selective attention.

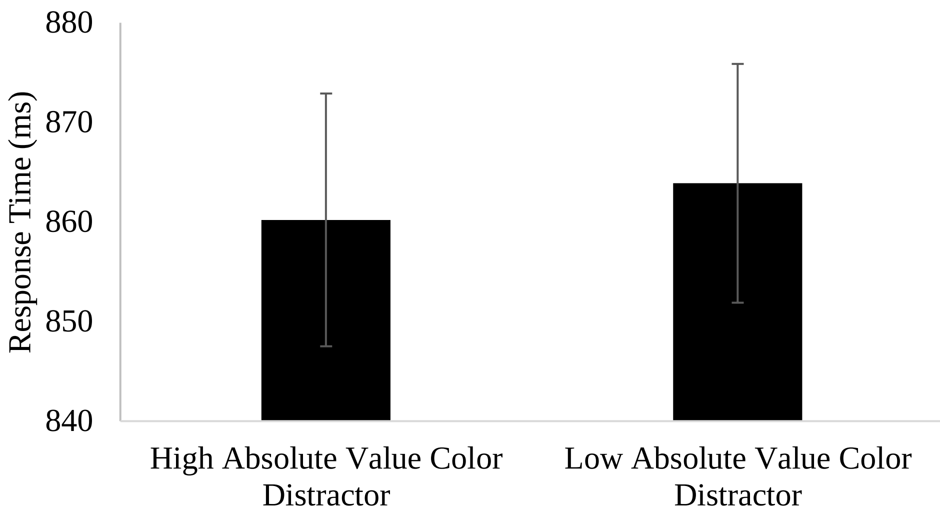


Figure 2.3**.** Mean of response times in the test phase of Experiment 2.
Error bars represent standard error of the mean.

General Discussion

The present study showed that the high relative reward value color distractor captured attention more than the low relative reward value color distractor when the absolute value of them was the same (Experiment 1), indicating that the relative value influenced the allocation of attention. However, the high absolute reward value color distractor did not capture attention more than the low absolute reward value color distractor when the relative value of them was the same (Experiment 2), indicating little impact of the absolute value on the allocation of attention. This is the first study in the value-driven attentional capture literature to test the impacts of absolute and relative values through the independent manipulation of absolute and relative values and to confirm the critical role of relative value in value-driven attentional capture.

The present study demonstrates that relative value is learned within an immediate context rather than a general or broad context. The context, in which the relative value of colors was determined, was specific to blocks in which the colors were presented, rather than the whole training session. This was because relative value is set by a reference point (Kahneman & Tversky, 1979), and in the present study a reference point of the red and green was within the blocks where the colors were presented as targets. For example, in block 1 of Table 2-1, targets are red and yellow. Accordingly, participants search for both colors during block 1, allowing each of them to be a reference point for the other to compare their values. In block 2, however, targets are green and blue, but neither red nor yellow. Therefore, it is unlikely that participants unnecessarily think about red and yellow in block 2 because these colors are non-target colors. Likewise, in block 1, participants would not search for green and blue because these colors are not task relevant during block 1. Thus, the context for value-driven attentional capture operates within a set of trials where a color is task relevant, and the context used to establish the relative value does not extend beyond to trials where the color is no longer task relevant.

In line with Vincent (2011), the present study showed that prospect theory can extend to early cognitive stages of processing. However, while Vincent (2011) addressed the weighting function of prospect theory, the current research investigated the reference dependence in the value function of prospect theory. According to reference dependence (Kahneman & Tversky, 1979), the subjective value depends on a reference point so that the relative value of an object compared to its reference's value is critical. In line with the reference dependence, the current study showed that the value-driven attentional capture was stronger for the color whose value was larger compared to the reference color's value than the color whose value was smaller compared to the reference color's value.

The impact of relative value for reward aligns with the importance of context in the value-driven attentional capture effect. Value-driven attentional capture relies on the context in which the stimuli-reward associative learning occurs. Specifically, a stimulus captures attention in a background scene where the stimulus was previously valuable more than in another scene where the stimulus was not (scene contexts, Anderson, 2015). Furthermore, predictive relationships between stimuli and reward are necessary for value-driven attentional capture (predictability contexts, Sali, Anderson, & Yantis, 2014), because dopaminergic prediction errors, calculated in the predictive relationships, serve as teaching signal that establish value-driven attentional capture (Anderson, 2019). In line with the importance of context in these previous findings, the present study showed the importance of contexts for the reward value. Value-driven attentional capture occurs on the basis of relative value which is determined by a reference point. A reference point can change depending on contexts (reference dependence contexts, Kahneman & Tversky, 1979).

A critical role of a relative property across different cognitive stages has been found in other research, such as relational theory. According to relational theory (Becker et al., 2010; Goldstein & Beck, 2016), an attention control setting is established depending on a relation between a target and distractor (a reference) near to the target. For example, when an orange target is presented with yellow distractors, an attentional control setting is adjusted to “redder” (a relative property) rather than “orange” color (an absolute property), suggesting that a relative reference not involving reward values can influence selective attention. Although the references in relational theory do not involve reward values, relational theory is consistent with the current study and prospect theory in that relative rather than absolute properties are critical in earlier and later cognitive stages.

In conclusion, the present study contributes the understanding of value-driven attentional capture and prospect theory. The mechanism of valuable stimuli receiving attentional priority is on the basis of the relative values of the reward. Reference dependence, the key premise of prospect theory, operates in the earlier cognitive stage, selective attention. Future research may allow generalization to tasks using monetary rewards because absolute value of real money may be more salient than non-monetary rewards, and prospect theory was demonstrated using both monetary and non-monetary outcomes (Tversky & Kahneman, 1981).

Chapter 3: Diminishing Sensitivity in Value-Driven Attention

Prospect Theory in Selective Attention

Decision-making is the process of making a choice among available alternatives (Edwards, 1954). Similarly, a selection process exists in perception via selective attention, the process of focusing on a particular stimulus out of many alternatives (Broadbent, 1958; Kahneman, 1973; Treisman & Geffen, 1967). That is, although decision-making and selective attention occur in different cognitive stages, they share a core concept of selection. Furthermore, the selection processes interact functionally. Attending to an item leads to an increase in the likelihood of choosing the item (Krajbich, Armel, & Rangel, 2010; Stewart, Hermens, & Matthews, 2016), and the decision to search for an item facilitates attention toward the item (Desimone & Duncan, 1995; Wolfe, 1994). In addition to the conceptual similarity and functional link, decision-making and selective attention share a critical factor affecting selection, *value*. More valuable items are more likely to be chosen in decision-making (Von Neumann & Morgenstern, 1947) and are more likely to be attended to in perception (Berridge & Robinson, 1998). However, decision-makers do not objectively evaluate the value of items, but distort it (Kahneman & Tversky, 1979; Thaler, 1980). The value distortion in decision-making occurs in a predictable way according to the psychological principles in the value-function of prospect theory (Tversky & Kahneman, 1981). Then, the critical question is if the value distortion found in decision-making will occur in selective attention. Accordingly, the present study investigates whether when a valuable item attracts attention, the value of the item is distorted on the basis of the diminishing sensitivity principle of prospect theory (Kahneman & Tversky, 1979).

Prospect Theory in Selective Attention

Traditional economic theory suggests how decision-makers should behave to maximize benefits. It postulates that decision-makers are rational and should choose the most valuable alternative. As a result, economic theory does not fit with how people actually make a choice. To explain how decision-makers actually behave, prospect theory (Kahneman & Tversky, 1979) posits that decision-makers are irrational and explains how objective (absolute, mathematical) value (e.g., money, time, health) is distorted due to the psychological principles: reference dependence, diminishing sensitivity, and loss aversion. The principles are described in the value-function (see Figure 3-1). According to reference dependence, value is determined from a reference point so that relative value (e.g., higher, lower), but not absolute value (e.g., $5, 100 points, 10 minutes), is critical. A reference point can move and multiple reference points may exist depending on a given situation. Diminishing sensitivity suggests that the proportion of a difference is critical so that earning an additional $5 leads to more pleasure when $10 was expected than when $100 was expected (15:10>105:100). The difference between $10 and $15 looms bigger psychologically than the difference between $100 and $105, although the objective (mathematical) difference is the same. Loss aversion suggests that people are more sensitive to potential losses than gains. Prospect theory has been extensively validated and used in economics, marketing, and politics because it predicts how people *actually* make a decision (Barberis, 2013). Kahneman was awarded the 2002 Nobel Memorial Prize in Economics for developing prospect theory, and Tversky would surely have shared the prize if he had not passed away in 1996 (Barberis, 2013). The 2017 Nobel Memorial Prize winner in Economics, Richard Thaler, played a pivotal role in applying prospect theory to economics and establishing the field of behavioral economics (Kahneman, 2011).

Interestingly, Kahneman and Tversky took advantage of basic principles (e.g., Weber-Fechner law) of perception to develop prospect theory. The two psychologists drew from the understanding that basic cognitive principles operate across the early (perception) and later (decision-making) cognitive stages. For example, Kahneman and Tversky stated,

> An essential feature of the present theory is that the carriers of value are changes in wealth or welfare, rather than final states. This assumption is compatible with basic principles of perception and judgment. Our perceptual apparatus is attuned to the evaluation of changes or differences rather than to the evaluation of absolute magnitudes. When we respond to attributes such as brightness, loudness, or temperature, the past and present context of experience defines an adaptation level, or reference point, and stimuli are perceived in relation to this reference point. . . . The same principle applies to non-sensory attributes such as health, prestige, and wealth. (Kahneman & Tversky, 1979, p. 277)

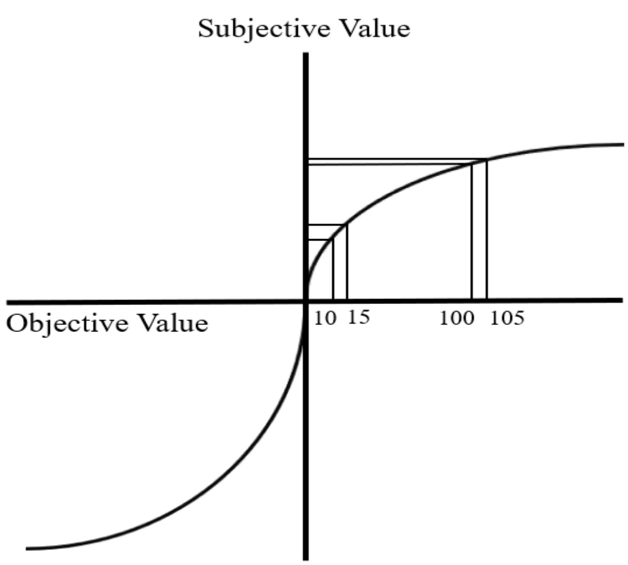


Figure 3.1. A typical value-function of prospect theory.

Value-function describes how objective value (absolute value, mathematical value, outcomes) is psychologically (subjectively) distorted.

This statement, in line with Thaler (1980, 1999), indicates that prospect theory may extend to selective attention. In addition, the probability weighting function (another aspect of prospect theory) was demonstrated to operate in selective attention (Vincent, 2011). Also, decision-making and selective attention share a core concept of selection (Edwards, 1954; Kahneman, 1973) and interact functionally (Desimone & Duncan, 1995; Krajbich et al., 2010). These allude to the extendibility of the value-function to selective attention. In line with this, Kim and Beck (2020b) demonstrated the reference dependence principle of prospect theory is present in selective attention.

Reference Dependence in Selective Attention

Reference dependence suggests that the value of an object is determined by a reference point of the object. For example, when you have expected to gain $1, receiving $10 will give rise to pleasure. When you have expected to gain $20, receiving $10 will lead to disappointment. The reference points of 1 and 20 determine the subjective value of 10. That is, prospect theory suggests that relative value (high or low compared to a reference point), not absolute value ($10), is critical to perceived value.

Kim and Beck (2020b) demonstrated that reference dependence operates in selective attention by applying the reference dependence principle to value-driven attentional capture. Value-driven attentional capture (Anderson, Laurent, & Yantis, 2011; Bucker & Theeuwes, 2017; Chelazzi, Perlato, Santandrea, & Della Libera, 2013; Della Libera & Chelazzi, 2009; Hickey, Chelazzi, & Theeuwes, 2010; Lee & Shomstein, 2014; Le Pelley, Pearson, Porter, Yee, & Luque, 2019; Mine & Saiki, 2015; Roper, Vecera & Vaidya, 2014) suggests that more valuable stimuli are attended more. Therefore, value-driven attentional capture is useful for

exploring whether more valuable stimuli are attended more based on the value function (the psychological principles) of prospect theory. However, the classic paradigm of value-driven attentional capture (Anderson, 2016) is not sufficient to test if the value function of prospect theory applies to selective attention.

The classic paradigm of value-driven attentional capture consists of training and test phases (e.g., Anderson et al., 2011). In a typical training phase where associative learning between color and reward occurs, search targets are red and green. One of the two target colors is randomly selected and presented among different color stimuli on each trial. Therefore, both target colors are potential targets on each trial during the training phase. After locating the target (either red or green), participants are asked to report whether the orientation of a line inside the target is horizontal or vertical by pressing a corresponding key. Response time for the pressing the key is measured. Reward is given for a correct response. Critically, red is associated with high reward, and green with low reward (color-reward associations counterbalanced across participants). In a typical test phase, it is examined if the more valuable color (red), previously associated with higher reward in training, captures attention more than the less valuable color (green), previously associated with lower reward in training. In the test phase, color is task irrelevant because search targets are unique shapes (e.g., a white diamond among white circles, a white circle among white diamonds). Critically, on some trials, one of the set of distractors is equiprobably either red or green. Despite color being task-irrelevant and no reward given in the test phase, search is slower when red distractors, the previously high-valued color in training, are presented than when green distractors, the previously low-valued color in training, are presented. The delay with the high-valued compared to low-valued color distractors suggests that more valuable stimuli attract attention more.

The results of the classic paradigm, however, can not demonstrate if the value-driven attentional capture effect was due to relative or absolute value (Anderson, 2016). The test target colors (red and green) are reference points for one another during the training phase in the classic paradigm. Red is both absolutely and relatively high compared to green, making the classic paradigm unable to answer whether high-valued color distractors capture attention more because they are associated with a higher relative or absolute value.

Kim and Beck (2020b) demonstrated that reference dependence operates in selective attention by modifying the classic paradigm to allow for reference dependence to be tested. Unlike in the typical value-driven attention capture paradigm, in Kim and Beck's (2020b) task the test target colors (red and green) had different reference points in the training phase. For example, while target colors were red and yellow in blocks 1, 3, and 5, they were green and blue in blocks 2, 4, and 6. Accordingly, red and green had yellow and blue reference points respectively in the training. This allows for the independent manipulation of the relative and absolute value of the to-be-tested color (red and green). In the test phase, red and green were presented as distractor colors like the classic paradigm. The authors found evidence for attention capture, slower search, when the high-valued color was relatively high but not when it was absolutely high. The findings suggest that more valuable stimuli receive higher attentional priority due to relative but not absolute value, and reference points play a critical role in determining subjective value (reference dependence).

Diminishing Sensitivity in Selective Attention

The diminishing sensitivity principle reflects the basic psychological principle of the Weber-Fechner law which states that people respond to changes in physical stimuli by

comparing the changed value to the original value; therefore, a proportion of a difference is critical rather than an absolute difference (Thaler, 1980, 1999). For example, it is easier to notice the difference between 1kg and 2kg than between 10kg and 11kg (Stevens, 1957). In line with this, the value-function of prospect theory shows that the marginal impact of a change diminishes with the distance from a regular reference point of 0 (Kahneman & Tversky, 1979).

The diminishing sensitivity principle has been demonstrated empirically in judgment and decision-making tasks. Thaler (1980) showed that $5 seems like a lot to save on a $25 radio but not much on a $500 TV. The difference between 20 and 25 looms larger than the difference between 495 and 500 although the actual difference is the same, $5. This seminal finding was replicated in Tversky and Kahneman (1981), where people were more sensitive to the difference between $10 and $15 than between $120 and $125, indicating the difference between 10 and 15 was psychologically larger than the difference between 120 and 125. The present study examines if diminishing sensitivity operates in selective attention by applying the empirical fining (Thaler, 1980; Tversky & Kahneman, 1981) to the modified value-driven attentional capture paradigm (Kim & Beck, 2020b).

Experiment 1

In the training phase (see Figure 3-2), associative learning occurs between color and reward. In the context blocks 1, 3, and 5 of the training phase, one of two target colors (e.g., red, yellow) was randomly chosen and presented on each trial. One target color (e.g., red) gave 100 points, and the other target color (e.g., yellow) gave 1 point on each trial when a correct response was made. Therefore, the 100 color (red) and the 1 color (yellow) were potential targets simultaneously and so became reference points for each other. In the context blocks 2, 4, and 6, one of two target colors (e.g., green, blue) was randomly presented on each trial. One target color (e.g., green) gave 1000 points, and the other target color (e.g., blue) gave 901 points. Therefore,

the 1000 color (green) and the 901 color (blue) were potential targets simultaneously and so became reference points for each other.

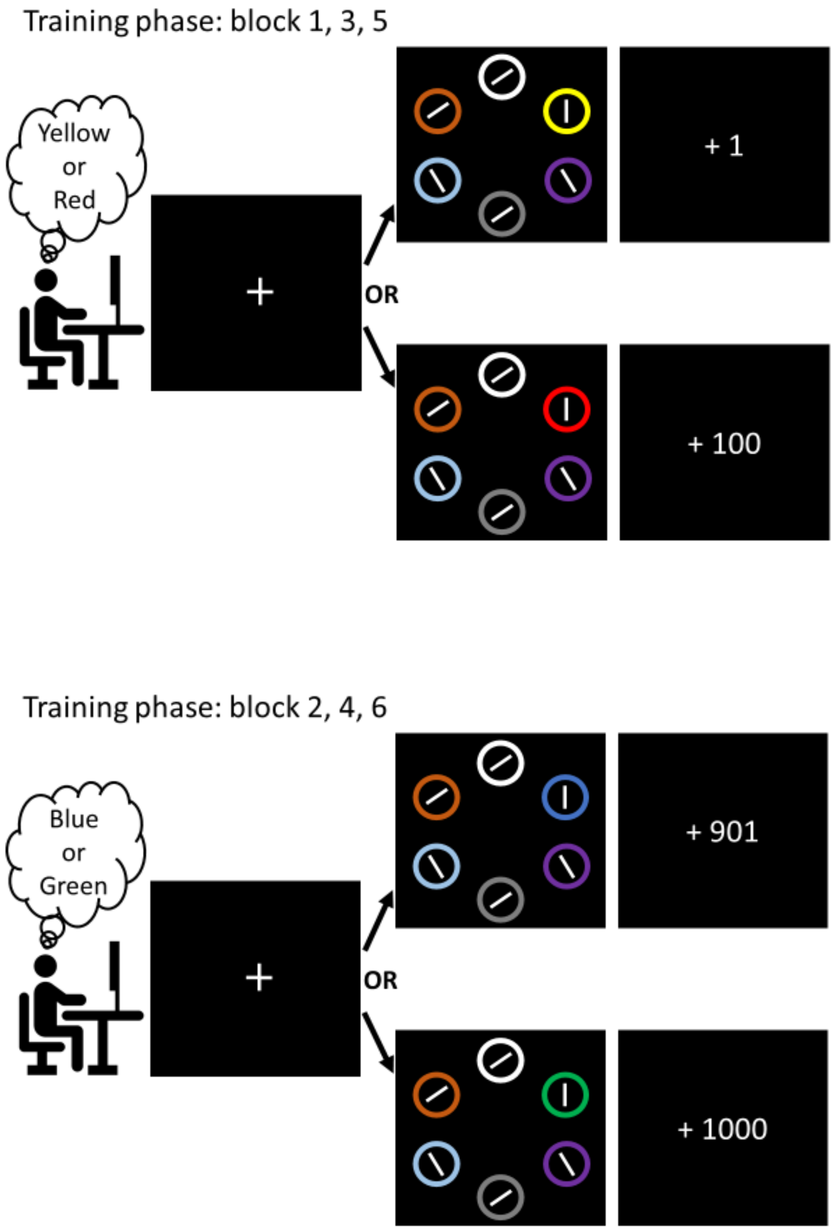


Figure 3.2. Examples of the training phase in Experiment 1.

In blocks 1, 3, and 5, search targets are yellow and red, giving 1 point and 100 points, respectively. In blocks 2, 4, and 6, search targets are blue and green, giving 901 points and 1000 points, respectively.

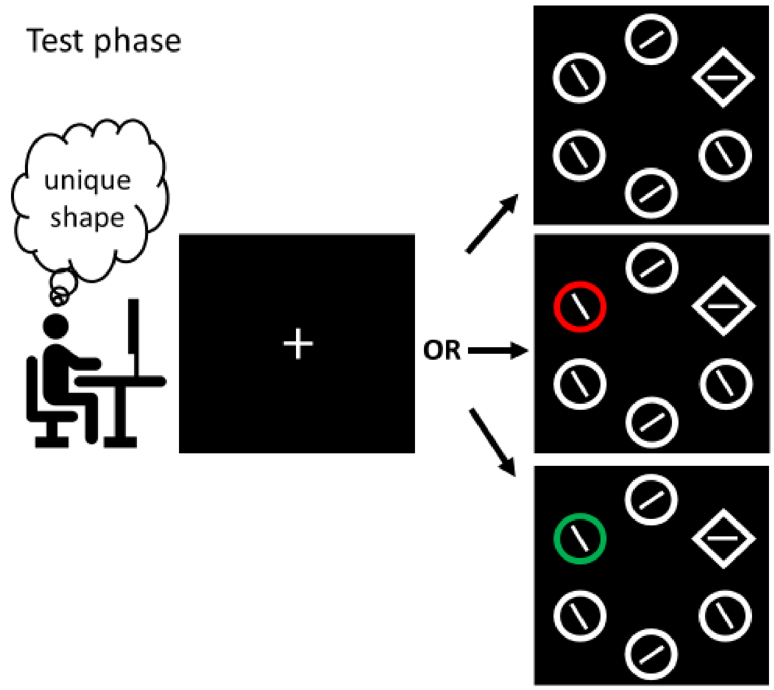


Figure 3.3. Examples of the test phase.

Search targets are unique shape. On a half of trials, no color distractor is presented (top). On the remaining half, one of distractors is equiprobably either red (middle) or green (bottom). No reward is given in the test phase.

In the test phase (see Figure 3-3), search targets were defined by a unique shape; therefore, color was task-irrelevant. Also, no reward was given in the test phase. Critically, on some trials, one of the set of distractors was either red (which had been the 100-point color with the reference point of the 1 point color in the training phase) or green (which had been the 1000-point color with the reference point of the 901-point color in the training phase). According to the diminishing sensitivity principle (Kahneman & Tversky, 1979; Thaler, 1980), the difference between 100 and 1 should be psychologically bigger than the difference between 1000 and 901 although the objective (absolute) difference is the same. If the diminishing sensitivity principle operates in selective attention, the 100-point color distractor should attract attention more than

the 1000-point color distractor. Accordingly, search should be delayed more when the 100-point color distractor is presented than when the 1000-point color distractor is presented.

Method

Participants. Seventy-two undergraduate students with normal or corrected-to-normal vision participated for course credit (mean age =19.3, 51 female). The sample size was determined from the Kim and Beck (2020b) study. The critical analysis to assess value-driven attentional capture was a comparison of response times in the test phase between trials with the high value color distractors and trials with the low value color distractors. G power (power = 0.70, alpha = 0.05, and Cohen's D = 0.30) for the critical comparison between high and low value color distractors in the test phase in Kim and Beck showed that at least 71 participants were needed.

Apparatus and Stimuli. Stimuli were presented on a 20-inch monitor. The distance between the participants and the monitor was approximately 60 cm but was not constrained. Experiments were programmed and administered using MATLAB and Psychophysics Toolbox software.

In the training phase (see Figure 3-2), each trial consisted of fixation, search, blank, and feedback displays. The background of the screen was black for all displays. In the fixation display, a white cross bar was presented in the center of the screen. In the search display, six circles (1.4° diameter each) were presented around an invisible circle (5° radius). Inside a target object, a horizontal or vertical white line was presented, and inside each distractor object, a white line tilted 45° to the left or right was presented. One of the six circles was a target color (yellow, red, green, or blue) and the others were distractor colors (orange, purple, aqua, white, and gray). In the search display of the test phase (see Figure 3-3), the search target was a unique shape: a

circle among diamonds or a diamond among circles. On half of the trials, all of the objects were white. On the other half of trials one of non-target objects was equiprobably either red or green.

Design. The experiment consisted of 720 training trials followed by 384 test trials. The independent variable is the value of the test target colors. In the training phase, correct responses earned 100 and 1000 points for the test target colors, red and green, respectively (the reverse association for half of participants). For the reference target colors, correct response earned 1-point and 901-point for blue and yellow, respectively (the reverse association for half of participants). The 100-point test target and the 1-point reference target were presented in blocks 1, 3, and 5 (in blocks 2, 4, and 6 for half of participants). The 1000-point test target and the 901-point reference target were presented in blocks 2, 4, and 6 (in blocks 1, 3, and 5 for half of participants). Within each block, each of the two target colors (one test target color and one reference target color) were presented on 50% of trials. The test target colors (red or green), the reference target colors (yellow or blue), and the block order were fully counterbalanced across the participants. Therefore, stimuli differences were controlled between the 100 and 1000-point test targets, and proximity from the training to test phase was controlled between the test targets.

Procedure. In the training phase, participants were instructed to find a circle with one of the two target colors and report the orientation of the line inside the circle by pressing the N-key for a horizontal line or M-key for a vertical line as quickly and accurately as possible. On each trial, the fixation display was presented for 400ms, followed by the search display until a response was made. After the response, there was a blank display for 50ms and then a feedback display for 900ms. In the feedback display, earned points (e.g., + 100) were presented when a correct response was made within 1500ms. For incorrect responses, '+ 0 (wrong)' was presented. For slow responses (over 1500 ms), '+ 0 (too slow)' was presented.

Participants first completed 40 practice trials during the training phase. In the first 20 practice trials, the target colors were the same as the target colors in the 1st, 3rd, and 5th training blocks (e.g., red and yellow). In the second 20 practice trials, the target colors were the same as those of 2nd, 4th, and 6th training blocks (e.g., green and blue). Before each practice, oral and written instructions regarding the target colors were provided. Before each of the six training blocks, written instruction regarding the target colors was provided. Participants were informed that they would receive points when fast and correct responses were made, and the experiment would finish earlier as they received more points. However, unbeknownst to the participants, earned points did not affect the number of trials in the experiment.

The test phase followed immediately after the training phase, participants were instructed to search for a unique shape (a circle among diamonds or a diamond among circles) and report the orientation of the line in the unique shape; therefore, color was task-irrelevant. Also, they were informed that reward points were not given in the test phase. The timing of each screen and required response was the same as in the training phase, but the search display was replaced with the shape singleton search display. During 20 practice trials, an experimenter checked and confirmed that participants understood the singleton shape detection instructions. Then, 384 randomly ordered test trials were given. On 96 of the 384 trials, one of non-target objects was green. On another 96 trials, one of the non-target objects was red. On the remaining 192 trials, all objects were white.

Results

The dependent variables are accuracy and response time (RT) recorded from the onset of the search display. Only correct responses were included in analyses of RTs (incorrect trials: 4.1% in training phase and 6.9% in test phase). Also, trials in which RT was shorter than 150ms

(<.01% in training phase, <.01% in test phase) or longer than 1500ms (1.1% in training phase, 4.6% in test phase) were excluded from the analysis. The first three trials of each block in the training phase and of the test phase were also excluded from the analysis to allow some time to change the attentional control settings.

Training phase. Mean accuracy was not different between when the target was the 100 (compared to 1) color (*M* = 95.7%, *SE* = .3%) and the 1000 (compared to 901) color (*M* = 96.0%, *SE* = .3%), *t*(71) = .96, *p* = .34, *d*=.11. Mean RT was not different between when the target was the 100 (compared to 1) color (*M* = 684 ms, *SE* = 9 ms) and the 1000 (compared to 901) color (*M* = 673 ms, *SE* = 10 ms), *t*(71) = 1.90, *p* = .062, *d*=.22.

Test phase. A one-way within-subjects ANOVA on mean RT and mean accuracy was conducted to explore how the three distractor conditions (100 color distractors, 1000 color distractors, no color distractors) influenced search.

For accuracy, the distractor conditions marginally influenced accuracy of search, *F*(2, 142) = 2.55, *p* = .08, η_p^2 =.035. Planned comparisons revealed that mean accuracy was lower when the 100 color distractors (*M* = 92.9%, *SE* = .5%) were presented than when no color distractors were presented (*M* = 93.8%, *SE* = .4%), *t*(71) = .2.29, *p* = .025. Mean accuracy was not significantly lower when the 1000 color distractors (*M* = 93.1%, *SE* = .4%) were presented than when no color distractors were presented (*M* = 93.8%, *SE* = .4%), *t*(71) = 1.63, *p* = .108. Mean accuracy was not different between the 100 color (*M* = 92.9%, *SE* = .5%) and 1000 color (*M* = 93.1%, *SE* = .4%) distractors, *t*(71) = .50, *p* = .61, *d*=.06.

For RT (see Figure 3-4), the type of distractor influenced RT of search, *F*(2, 142) = 193.91, *p* < .001, η_p^2 =.73. Planned comparisons revealed that mean RT was higher when the 100 color distractors (*M* = 865 ms, *SE* = 10 ms) were presented than when no color singleton

distractors (*M* = 783 ms, *SE* = 9 ms) were presented, $t(71) = 18.21$, $p < .001$. Mean RT was higher when the 1000 color distractors (*M* = 855 ms, *SE* = 10 ms) were presented than when no color distractors were presented (*M* = 783 ms, *SE* = 10 ms), $t(71) = 15.61$, $p < .001$. The slower RTs reflect the bottom-up capture interferences by the singleton color distractors. Most importantly, mean RT was slower when the 100 color distractors were presented than when the 1000 color distractors were presented, $t(71) = 2.27$, $p = .026$, d=.27 (see Figure 3-4). The findings imply that the 100 color distractor captured attention more than the 1000 color distractor. This delay is further supported by Bayes analysis: Bayes Factor (BF_{+0}) = 4.41 (van Doorn et al., 2019) indicated that the prediction of more attentional capture by the 100 (compared to 1) color distractor than the 1000 (compared to 901) color distractor, was 4.41 times more favored than the null.

Discussion

Search was delayed more so when the 100-point color distractors were presented than when the 1000-point color distractors were presented, suggesting that the 100-point color distractors captured attention more than the 1000-point color distractors. This finding is in line with the previous findings of Thaler (1980) and Tversky and Kahneman (1981). The proportional distance between 100 and its reference point 1 is larger than the proportional distance between 1000 and its reference point 901 (100:1 > 1000:901). Therefore, according to diminishing sensitivity, the difference between 1 and 100 should loom larger than the difference between 901 and 1000 although the absolute difference (100-1=1000-901) was the same. Accordingly, the results of Experiment 1 demonstrated that the diminishing sensitivity principle of prospect theory operates in selective attention.

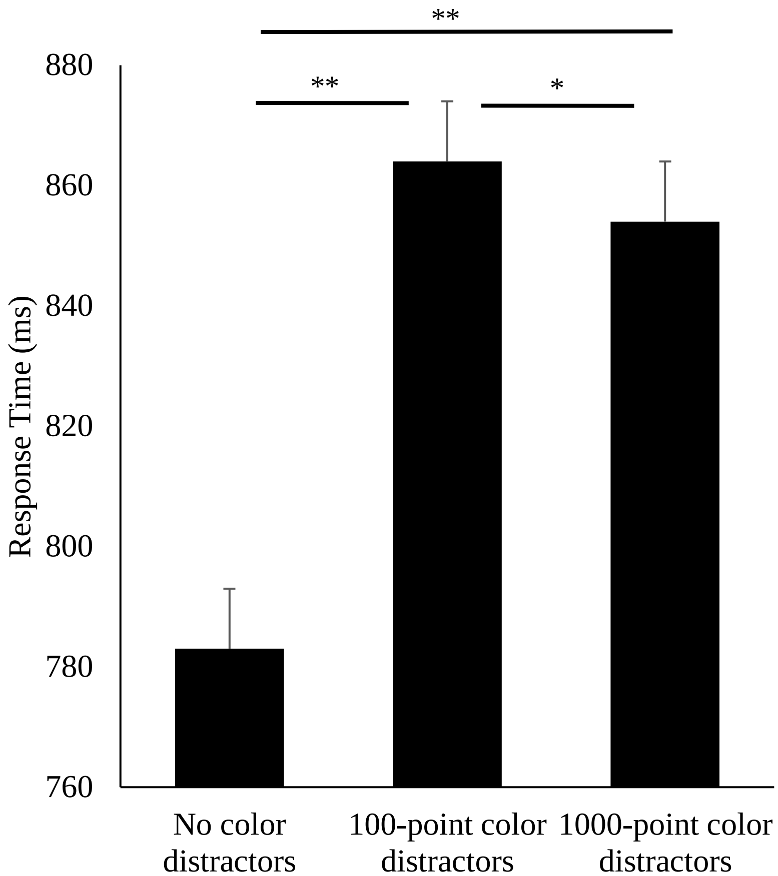


Figure 3.4. Response times of the test phase in Experiment 1.

Error bars represent standard error of the mean. * and ** indicate p<.05 and p<.001, respectively.

Experiment 2

In line with the findings of more sensitivity to the difference between $10 and $15 than $120 and $125 (Tversky & Kahneman, 1981) and more sensitivity to the difference between $20 and $25 than $495 and $500 (Thaler, 1980), Tversky and Kahneman (1981) and Thaler (1980) suggested the hypothesis that the effort to save $5 on a $50 purchase would be similar with the effort to save $15 on a $150 purchase due to the same proportion (50:5=150:15). In addition, Kahneman and Tversky (1982) suggested that the amount of money required for someone to forego a 50 percent chance of winning $100, $200, $500, $1000, and $2000 are roughly

proportional to the size of the bet. For example, to forego a 50 percent chance of $100, someone would need roughly $35 and to forego a $1000 bet they would need roughly $350. Thus, as the size of the stake has increased by a factor of 10, the amount needed to forego the bet increases by almost the same factor. The proportional nature of value seen in prospect theory is consistent with the Weber-Fechner law. The same proportion hypothesis, that the proportion of the money saved is more important than the absolute value saved (Kahneman & Tversky, 1982; Thaler, 1980; Tversky & Kahneman, 1981), was subsequently verified in various scenarios empirically and computationally in monetary and non-monetary domains (Azar, 2011; González-Vallejo, Harman, Mullet, & Sastre, 2012; see González-Vallejo, 2002, for a review).

Azar (2011), demonstrated the importance of proportional value in pricing goods. When participants knew the price of the high-quality good, they were asked to provide the maximal price of the low-quality good for which they would prefer the low-quality good. That is, at what price for the low-quality good would the participants be indifferent between the goods? Critically, the price of the high-quality good was manipulated between a high or low price. For example, when the price of the 15" laptop (a high-quality good) was 11,250 Shekels, the mean of the maximal price of the 13" laptop (a low-quality good) was 2,938 Shekels. When the price of the 15" laptop (a high-quality good) was 3,750 Shekels, the mean of the maximal price of the 13" laptop (a low-quality good) was 903 Shekels. The ratio (0.26) between 2,938 and 11,250 was not statistically different from the ratio (0.24) between 903 and 3,750. Namely, the difference between 2,938 and 11,250 looms similar to the difference between 903 and 3,750 because both differences reflect the same proportional difference between the 13" and 15" laptops. This finding suggests that the proportion of the difference is critical, in line with Tversky and Kahneman (1981) and Thaler (1980).

Experiment 2 investigates if the same proportion hypothesis operating in decision-making (a similar effect of the difference between 5 and 50 and the difference between 15 and 150, Kahneman & Tversky, 1982; Thaler, 1980; Tversky & Kahneman, 1981) operates in selective attention. Therefore, in the training phase, the 100-point and 1000-point target colors have 1-point and 10-point reference target colors, respectively. According to the same proportion hypothesis, the difference between 1 and 100 should be similar with the difference between 10 and 1000 due to the same proportion (100:1=1000:10). Based on this hypothesis, in the test phase search time should not be different between when the 100 color distractors were present and when the 1000 color distractors were present.

Method

Participants. Based on the same power analysis for Experiment 1, 72 undergraduate students (mean age=19.5, 61 female) with normal or corrected-to-normal vision participated for course credit.

Apparatus, Stimuli, Design, and Procedure. The apparatus, stimuli, design, and procedure were identical to Experiment 1. The only difference was the reward point allocation during training. In the training phase, the 100-point and 1000-point test color targets have the 1-point and 10-point reference color targets respectively. Like Experiment 1, the test target colors (red or green), the reference target colors (yellow or blue), and the block order were fully counterbalanced across the participants. Thus, both stimuli differences and proximity from the training to test phase were controlled between the test target colors.

Results

Like Experiment 1, incorrect trials (5.4% in training phase and 8.5% in test phase), trials in which RT was shorter than 150ms (<.01% in training phase, <.01% in test phase), and trials in

which RT was longer than 1500ms (1.2% in training phase, 5.0% in test phase) were excluded from the analysis.

Training phase. Mean accuracy was not different between when the target color was 100 (compared to 1, *M* = 95.9%, *SE* = .5%) and 1000 (compared to 10, *M* = 96.0 %, *SE* = .5%), *t*(71) = .76, *p* = .45, *d* =.09. Mean RT was not different between when the target color was 100 (*M* = 684 ms, *SE* = 9 ms) and 1000 (*M* = 676 ms, *SE* = 9 ms), *t*(71) = 1.42, *p* = .17, *d* =.17.

Test phase. As in Experiment 1, a one-way within-subjects ANOVA on mean RT and mean accuracy was conducted to explore how the three distractors (100 color distractors, 1000 color distractors, no color distractors) influenced search.

For accuracy, the type of distractor affected search accuracy, *F* (2,142) = 7.0, *p* = .001, η_p^2 =.09. Post hoc comparisons revealed that accuracy was lower when the 100 distractors (*M* = 91.1%, *SE* = .6%) appeared than when no distractors (*M* = 92.7%, *SE* = .5%) appeared, *t*(71) = 4.16, *p* < .001. Accuracy was lower when the 1000 distractors (*M* = 91.7%, *SE* = .6%) appeared than when no distractors (*M* = 92.7%, *SE* = .5%) appeared, *t*(71) = 2.42, *p* = .018. Mean accuracy was not different between when the 100 distractors (*M* = 91.1%, *SE* = .6%) and the 1000 distractors appeared (*M* = 91.7%, *SE* = .6%), *t*(71) = 1.11, *p* = .27, *d* =.13.

For RT (see Figure 3-5), the type of distractor influenced RT of search, *F*(2, 142) = 192.2, *p* < .001, η_p^2 =.73. Planned comparisons revealed that mean RT was slower when the 100-point color distractors (*M* = 867 ms, *SE* = 10 ms) were presented than when no color distractors (*M* = 789 ms, *SE* = 9 ms) were presented, *t*(71) = 18.44, *p* < .001. Mean RT was slower when the 1000-point color distractors (*M* = 865 ms, *SE* = 10 ms) were presented than when no color distractors (*M* = 789 ms, *SE* = 9 ms) were presented, *t*(71) = 16.04, *p* < .001. Importantly, mean RT was not different between when the 100-point color distractors (*M* = 867 ms, *SE* = 10 ms)

were presented and when the 1000-point color distractors (*M* = 865 ms, *SE* = 10 ms) were presented, $t(71) = .61$, $p = .54$, $d = .07$ (see Figure 3-5), suggesting that the strength of the attentional capture for the two color distractors was similar. The conclusion is further supported by Bayes analysis of how the null is supported over the alternative hypothesis: Bayes Factor (BF_{01}) = 3.07 (van Doorn et al., 2019). This indicates that the prediction of the strength of attentional capture being equivalent for the two distractors was 3.07 times more plausible than the prediction of the strength being higher for one of the distractors.

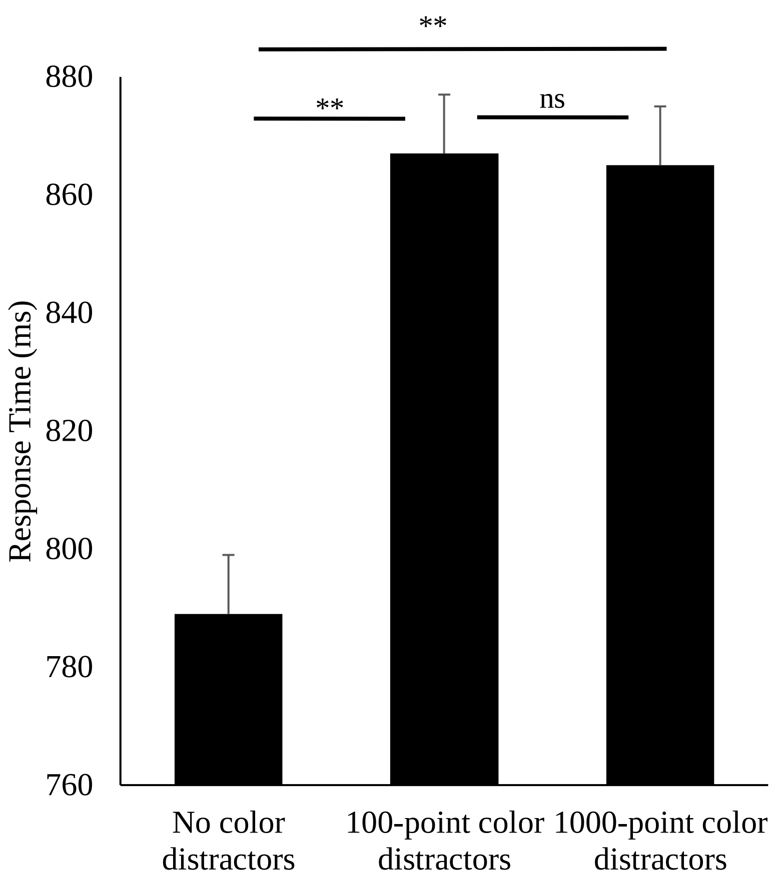


Figure 3.5. Response times of the test phase in Experiment 2.
Error bars represent standard error of the mean. ** indicates p<.001.

Discussion

Consistent with the proportion hypothesis, search speed was not different between when the 100-point color distractors were presented and when the 1000-point color distractors were presented. This finding suggests that the attentional capture effect of the distractors was similar because the difference between 1 and 100 and the difference between 10 and 1000 have the same proportion. Accordingly, Experiment 2 replicated the proportion hypothesis, which operates in decision-making (a similar difference between 5 and 50 to the difference between 15 and 150, Kahneman & Tversky, 1982; Thaler, 1980; Tversky & Kahneman, 1981), in selective attention. Also, the results of Experiment 2 are consistent with the Weber-Fechner law, the key foundation of diminishing sensitivity (Thaler, 1980, 1999). Thus, the diminishing sensitivity principle operates in selective attention.

General Discussion

The current study replicated the seminal findings for diminishing sensitivity from Thaler (1980) and Tversky and Kahneman (1981) in the modified value-driven attentional capture paradigm (Kim & Beck, 2020b). Experiment 1 showed that when the 100-point color and the 1000-point color were compared to the 1-point color and the 901-point color, respectively in the training phase, the 100-point color distractors captured attention more than the 1000-point color distractors in the test phase. The results of Experiment 1 are consistent with the previous findings (Thaler, 1980; Tversky & Kahneman, 1981) that the difference between $20 and $25 is psychologically larger than the difference between $495 and $500 although the mathematical difference is the same (Thaler, 1980) and that the difference between $10 and $15 is psychologically larger than the difference between $120 and $125 although the mathematical difference is the same (Tversky & Kahneman, 1981). Therefore, the former comparisons

(between 20 and 25, between 10 and 15) influenced decision-making more than the latter comparisons (between 495 and 500, between 120 and 125). In line with this, in Experiment 1, although the mathematical difference between 1 and 100 was the same as the mathematical difference between 901 and 1000, the psychological difference was larger between 1 and 100 than 901 and 1000. The former comparison (between 1 and 100) influenced selective attention more than the latter comparison (between 901 and 1000); accordingly, the 100-point color distractors attracted attention more than the 1000-point color distractors, demonstrating the diminishing sensitivity principle in selective attention.

Experiment 2 showed that when the 100-point color and 1000-point color were compared to the 1-point color and 10-point color respectively in the training phase, the 100-point color distractors and the 1000-point color distractors similarly captured attention in the test phase. The results of Experiment 2 are consistent with the same proportion idea (Thaler, 1980; Tversky & Kahneman, 1981) that the psychological difference between 5 and 50 is similar to that between 15 and 150 due to the same proportion. The former comparison (between 5 and 50) and the latter comparison (between 15 and 150) similarly influence decision-making; for example, the effort to save $5 on a $50 purchase would be similar with the effort to save $15 on a $150 purchase (Kahneman & Tversky, 1982; Thaler, 1980; Tversky & Kahneman, 1981). In line with this, in Experiment 2, the psychological difference between 1 and 100 was proportionally similar to the difference between 10 and 1000. Therefore, the former comparison (between 1 and 100) and the latter comparison (between 10 and 1000) influenced selective attention similarly; accordingly, the 100-point color distractors and the 1000-point color distractors captured attention similarly, indicating the diminishing sensitivity principle in selective attention.

Implications for Prospect Theory

There are previous studies (Kim & Beck, 2020b; Vincent, 2011) which show that prospect theory extends to selective attention. Kim and Beck (2020b) demonstrated that reference dependence operates in selective attention. The authors found that the value affecting the allocation of attention relied on a reference point of the value, suggesting that relative value, not absolute value, is critical in selective attention. Vincent (2011) demonstrated that the weighting function is applied in selective attention. According to the weighting function (Kahneman & Tversky, 1979), decision-makers overweight low expectation levels and underweight high expectation levels. Vincent (2011) found that during visual search, participants overweighted the probability of a search target appearing at a particular location when the probability was low while underweighted the probability when it was high. The patterns of the bias fit with the weighting function of prospect theory. In line with the previous studies, the current study further shows the extendibility of prospect theory to selective attention.

The current study replicated the seminal findings for the diminishing sensitivity principle from Kahneman and Tversky (1979) and Thaler (1980) through the modified value-driven attentional capture paradigm (Kim & Beck, 2020b), suggesting that the diminishing sensitivity principle operates in selective attention. This replication in attention is consistent with the Weber-Fechner law, the foundation of the diminishing sensitivity principle (Thaler, 1980, 1999). Therefore, the proportion of the differences between related outcomes is critical. In line with this, when the proportion of two related outcomes was different in Experiment 1 (100:1>1000:901), the larger proportional difference (100:1) attracted attention more than the smaller proportional difference (1000:901). When the proportion of differences was the same in Experiment 2 (100:1=1000:10), the two attracted attention similarly. Accordingly, the results of

Experiments 1 and 2 suggest that diminishing sensitivity occurs in decision-making and selective attention on the basis of a basic principle of perception (Kahneman & Tversky, 1979; Thaler, 1980, 1999).

The results of the current study reflect the reference dependence principle. According to reference dependence, a direction from a reference point is critical (e.g., 1000 is more than a reference point of 901). Therefore, relative value (e.g., higher) rather than absolute value (e.g., 1000 points) should be critical to determining psychological value (Kahneman & Tversky, 1979). If absolute value was critical, the 1000-point color distractors should have captured attention more than the 100-point color distractors in both Experiments 1 and 2. However, absolute value did not influence attentional allocation. Instead, the reference point colors (the 1 and 901 colors in Experiment 1, the 1 and 10 colors in Experiment 2) played a critical role to determining the value of the 100 and 1000 colors, showing that relative value is critical (reference dependence). Furthermore, the level of the relative value was determined according to the diminishing sensitivity principle: for example, in Experiment 1, although the relative value of both 100 (compared to 1) and 1000 (compared to 901) was high, the value of 100 was more than 1000 due to diminishing sensitivity. Therefore, the current findings are consistent with both the reference dependence principle and the diminishing sensitivity principle.

Implications for Value-driven Attentional Capture Literature

The previous studies using the classic value-driven attentional capture paradigm showed that a more valuable item attracts more attention (see Anderson, 2016; Failing & Theeuwes, 2018; Rusz, Le Pelley, Kompier, Mait, & Bijleveld, 2020 for a review). These findings are in line with the reference dependence and diminishing sensitivity principles. In the classic paradigm

(e.g., Anderson et al., 2011), associative learning between stimuli and reward for both a more valuable stimulus and a less valuable stimulus occurs in the same context (e.g., a training phase); accordingly, the two stimuli become reference points for one another. For example, when the more and less valuable stimuli are associated with 15 and 10 points, respectively, the objective values of the two will be subjectively represented as in Figure 3-1. Therefore, the findings in the previous literature that the more valuable stimulus (15) attracts attention more than the less valuable stimulus (10), do not violate the reference dependence and diminishing sensitivity principles.

The previous findings with the classic paradigm, however, could not demonstrate the principles of prospect theory. In the classic paradigm, the more valuable stimulus (15) is both absolutely and relatively high-valued compared to the less valuable one (10) because they are reference points for one another. Therefore, it is unclear if relative value (reference dependent), not absolute value, is critical to capturing attention (Anderson, 2016). Also, it is unclear if the psychological sensitivity is constant (linear), increases (convex) or decreases (concave) as objective value increases. Therefore, although the previous findings in the classic paradigm are in line with the principles of prospect theory, it was unknown whether the psychological value is distorted according to the principles of prospect theory.

In the value-driven attentional capture literature, the lack of exploration as to whether the value of items is distorted by the psychological principles captured in prospect theory, may be because prospect theory was researched largely in the economic literature (e.g., behavioral economics, Barberis, 2013); Kahneman and Thaler received Nobel Prizes in economics. Moreover, most studies in the value-driven attentional capture literature used the classic value-driven attentional capture paradigm, which does not allow the independent manipulation of

relative and absolute value (Anderson, 2016). However, reference dependence plays a critical role (e.g., each item having separate reference points) to testing the diminishing sensitivity principle in Kahneman and Tversky (1982), Tversky and Kahneman (1981), Thaler (1980), and the current study. The present study used the modified value-driven attentional capture paradigm (Kim & Beck, 2020b) because a reference point of each stimulus (color) can be manipulated independently like Kahneman and Tversky (1982), Tversky and Kahneman (1981) and Thaler (1980). Thus, the use of the modified paradigm allowed verification that value-driven attention occurs on the basis of reference dependence and diminishing sensitivity.

Summary and Conclusion

Summary

To understand how previous experiences drive attention, the dissertation addresses two outstanding questions: Why does contextual cueing occur rarely in non-spatial dimension? When valuable items attract attention, how are the values of the items determined?

In terms of contextual cueing, Chapter 1 showed that the shape-predicted color cues captured attention more than the non-predicted color cues, indicating the non-spatial context-driven search effect. More importantly, the non-spatial context-driven search effect occurred only after the two mismatch trials. This finding implies that expression of the non-spatial context-driven search may require cognitive resources more than the spatial context-driven search. However, the mechanism where the mismatch trials trigger the effect is unclear. Therefore, it should be further explored whether the context-driven search effect by the mismatch trials is due to conflict-driven cognitive control and/or exploratory attention.

In terms of value-driven attentional capture, Chapter 2 showed that relative value, not absolute value, influences the allocation of attention by using the modified value-driven attentional capture paradigm. The new paradigm allows the separate manipulation of relative and absolute value. In addition, Chapter 3 directly replicated the seminal findings for diminishing sensitivity from Thaler (1980) and Tversky and Kahneman (1981) in selective attention through the modified value-driven attentional capture paradigm (Kim & Beck, 2020b). The successful replications in selective attention align with the idea that the basic principles of perception are the foundation of prospect theory (Kahneman & Tversky, 1979; Thaler, 1980, 1999). Furthermore, Chapter 3 contributes to the understanding of the mechanism of value-driven

attentional capture, showing that the psychological value reflecting reference dependence and diminishing sensitivity, not objective value, plays a critical role in attentional allocation.

In addition, the dissertation suggests that the conditioning between color and reward in value-driven attention is Pavlovian rather than instrumental (Bucker & Theeuwes, 2017; Mine & Saiki, 2015). In all experiments in Chapters 2 and 3, attending to reward-associated-color distractors is always detrimental for task-performance in the test phase. Also, participants explicitly knew that the colors are always distractors and reward is never given during the test phase. Therefore, attentional capture by the color distractors suggests that the conditioning of value-driven attention is Pavlovian.

Locus of Attention

The idea that more attention is needed for the non-spatial context-driven search than the spatial context-driven search is consistent with Broadbent's attention theory (1958). He suggested that attention is needed to process identities of stimuli. In the spatial contextual cueing (Chun & Jiang, 1998), the configuration (spatial layout) of the search items is the context guiding attention. Identifying the configuration does not require processing the identity of each item. In other words, it is possible to know what context (spatial layout) is presented without identifying the identity of each item. In contrast, in the non-spatial contextual cueing (Chun & Jiang, 1999), the identities (shapes) of the search items are the context guiding attention to the predicted target identity (shape). Thus, identifying each item is necessary to know what context is presented. Thus, in line with the Broadbent's theory, more attention should be needed in the non-spatial contextual cueing because more identity information has to be processed in the non-spatial contextual cueing.

Late selection argues that information is selected after processing for meaning (Moray, 1959). Critically, however, when *multiple* items are less familiar (less encountered), the identities of the items are processed less automatically (Pashler, 1984). Therefore, in late selection, attention still modulates the processing of identity information of multiple items. In contextual cueing, multiple items are presented and predict target information (e.g., Chun & Jiang, 1998, 1999). Thus, the idea that attention plays a critical role in non-spatial contextual cuing, appears to be consistent with both early selection and late selection.

Future Direction

Prospect theory has contributed considerably to understanding the *actual* decision-making processes in various fields of society such as marketing, economics, and politics (e.g., Mental accounting, Thaler, 1999; Nudge effects, Thaler & Sunstein, 2009). Accordingly, the investigation of whether prospect theory extends to different cognitive stages could be similarly impactful. In line with this, outstanding questions are how the loss aversion principle is applied in selective attention, how the mechanism of selective attention reflecting the principles of prospect theory is implemented in the brain, and whether the allocation of attention appears optimal but is heuristic in nature (Gardner, 2019).

It should be noted that attention operates in both spatial and temporal dimensions; however, the dissertation investigates experience-driven attention within a spatial dimension. This is because the experience-driven attention literature has been little explored in a temporal dimension. But, there is a handful of evidence showing that previous search experiences (statistical learning) influence temporal attention (e.g., Olson & Chun, 2001). Therefore, it

should be further explored how previous experiences affect temporal attention to address whether or not experience-driven attention is specific to spatial attention.

Specifically, a growing body of evidence shows that selective attention samples stimuli rhythmically (temporal selective attention; Landau & Fries, 2012). For example, Landau and Fries (2012) showed that attention samples left and right locations rhythmically at around 4 Hz for each side (8 Hz for both). Furthermore, while one location is sampled, the other location is little sampled (alternative sampling). Yet, little is known about whether attentional rhythm is influenced by statistical learning. In line with this, outstanding questions are if the value-driven attention and the context-driven attention are applied in a temporal dimension. For example, when contexts (e.g., tone, background images) predict particular intervals when targets are presented, will attentional rhythm be modulated depending on the contexts? If more rewards are given when targets are presented in particular intervals, will attentional rhythm be adjusted for better detecting the targets in the high reward interval? Investigation of the questions will shed light on whether temporal attention and spatial attention are controlled under the same higher-level cognitive processes.

Conclusion

The dissertation contributes to the understanding of experience-driven attention. Contextual cueing and value-driven attentional capture are representative topics of the experience-driven attention literature. Previous evidence of contextual cueing was obtained largely when contexts were a spatial dimension but rarely when they were a non-spatial dimension (Goujon et al., 2015). In line with this, the dissertation shows non-spatial contextual cueing and explains the probable reason why the non-spatial contextual cueing was rarely found.

Non-spatial context-driven search was obtained after the mismatch trials, which likely cause an increase in attention to the context. This attentional boost is not necessary in spatial contextual cueing. Therefore, non-spatial than spatial context-driven search appears to require more attention. Although in value-driven attentional capture, “value” is a critical factor, little was known about how value of items is subjectively determined for the items guiding attention. The lack of exploration would be because prospect theory was researched largely in the economic literature; Kahneman and Thaler received Nobel Prizes in economics (Barberis, 2013). Furthermore, most studies in the value-driven attentional capture literature used the classic value-driven attentional capture paradigm, which does not allow the independent manipulation of relative and absolute value (Anderson, 2016). In line with this, the dissertation explores value-driven attention in the light of economic perspectives and reveals that the mechanism of value-driven attention is on the basis of prospect theory.

In conclusion, although it is clear that previous experiences influence selective attention (Awh et al., 2012), the mechanism remained unclear. Accordingly, the dissertation directly resolves the critical issues that were little addressed in the experience-driven attention literature. Thus, the dissertation further clarifies the mechanism by which previous experiences affect the allocation of attention.

Appendix A. ANOVAs for bins of 80 trials in Experiment 1 of Chapter 1

Experiment 1 ANOVAs for bins of 80 trials across experimental trials prior to the mismatch trials in Chapter 1.

	Trials	1-80	81-160	161-240	241-320	321-400	401-480	481-560	561-640	641-720	721-800
	F	0.032	1.4	0.4	1.479	2.368	2.721	0.019	0.079	0.179	3.326
Color	p	0.859	0.249	0.533	0.236	0.137	0.113	0.891	0.781	0.676	0.081
	η_p^2	0.001	0.057	0.017	0.06	0.093	0.106	0.001	0.003	0.008	0.126
	F	3.743	0.223	1.378	1.878	1.478	0.836	1.458	4.39	0.02	3.183
Validity	p	0.065	0.641	0.252	0.184	0.236	0.37	0.239	0.047	0.888	0.088
	η_p^2	0.14	0.01	0.057	0.075	0.06	0.035	0.06	0.16	0.001	0.122
	F	0.188	1.81	0.624	0.552	0.309	0.304	0.001	0.122	0.202	0.639
Interaction	p	0.669	0.192	0.437	0.465	0.583	0.587	0.98	0.73	0.658	0.432
	η_p^2	0.008	0.073	0.026	0.023	0.013	0.013	< 0.001	0.005	0.009	0.027

Appendix B. ANOVAs for bins of 80 trials in Experiment 2 of Chapter 1

Experiment 2 ANOVAs for bins of 80 trials across experimental trials prior to the mismatch trials in Chapter 1.

	Trials	1-80	81-160	161-240	241-320	321-400	401-480	481-560	561-640	641-720	721-800
Color	*F*	0.448	1.496	0.364	0.495	0.276	0.306	0.027	1.827	0.302	< 0.001
	p	0.51	0.234	0.552	0.489	0.605	0.585	0.87	0.19	0.588	0.992
	η_p^2	0.019	0.061	0.016	0.021	0.012	0.013	0.001	0.074	0.013	< 0.001
Validity	*F*	0.411	0.011	0.536	0.1	0.007	0.017	0.871	2.156	0.279	5.728
	p	0.528	0.916	0.471	0.755	0.935	0.898	0.36	0.156	0.603	0.025
	η_p^2	0.018	< 0.001	0.023	0.004	< 0.001	0.001	0.036	0.086	0.012	0.199
Interaction	*F*	0.124	0.598	0.71	0.028	3.794	0.947	6.034	0.629	0.384	0.033
	p	0.728	0.447	0.408	0.869	0.064	0.341	0.022	0.436	0.542	0.857
	η_p^2	0.005	0.025	0.03	0.001	0.142	0.04	0.208	0.027	0.016	0.001

Appendix C. ANOVAs for bins of 80 trials in Experiment 3 of Chapter 1

Experiment 3 ANOVAs for bins of 80 trials across experimental trials prior to the mismatch trials in Chapter 1.

	Trials	1-80	81-160	161-240	241-320	321-400	401-480	481-560	561-640	641-720	721-800
Color	*F*	5.563	0.459	3.427	1.590	0.039	0.811	0.294	0.444	1.107	0.505
	p	0.023	0.502	0.071	0.214	0.844	0.373	0.590	0.509	0.299	0.481
	η_p^2	0.115	0.011	0.074	0.036	0.001	0.019	0.007	0.010	0.025	0.012
Validity	*F*	0.732	3.976	1.014	3.068	0.139	0.932	0.021	3.800	1.298	0.102
	p	0.397	0.053	0.320	0.087	0.711	0.340	0.886	0.058	0.261	0.751
	η_p^2	0.017	0.085	0.023	0.067	0.003	0.021	<0.001	0.081	0.029	0.002
Interaction	*F*	1.610	0.241	0.002	<0.001	0.480	3.150	0.550	0.245	0.422	0.562
	p	0.211	0.626	0.965	0.999	0.492	0.083	0.462	0.623	0.519	0.457
	η_p^2	0.036	0.006	< 0.001	<0.001	0.011	0.068	0.013	0.006	0.010	0.013

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