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The perceptual enhancement by spatial attention is impaired during the attentional blink

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ABSTRACT

A salient, but task-irrelevant stimulus has long been known to capture attention in an automatic, involuntary manner. However, the automaticity of involuntary attention has recently been challenged. While some studies showed that the effect of involuntary attention depended on top-down attentional resources, other studies did not. To reconcile this conflict, we suggest to consider that attentional effect is not homogenous. Specifically, we hypothesized that the dependence of involuntary attention on top-down attention interacts with the presence/absence of the target location uncertainty and distractor interference. Consistent with this hypothesis, we found that when the attentional resources were depleted, the involuntary attention did not affect the perception of a single target stimulus (Experiment 1). However, when the target was accompanied by multiple distractors, evoking uncertainty regarding the target location, the involuntary attentional effect was observed, regardless of the availability of attentional resource (Experiment 2). This was so, even when the target location was always marked by a response cue, minimizing the target location uncertainty (Experiment 3). These findings provide a reconciliation for the theoretical debate regarding the dependence of involuntary attention on top-down attention and clarifies how perception is modulated by involuntary attention.

It has long been recognized that a novel, salient stimulus captures attention in an involuntary manner. This involuntary capture of attention has been well demonstrated by the cuing paradigm (Posner, 1980). In this paradigm, participants perform a task of detecting or identifying a prespecified target stimulus presented in periphery. Prior to the target presentation, a salient cue stimulus is presented in periphery. Importantly, in a type of trials, the cue is presented at the target location (valid trials), whereas in the other, the cue and the target are presented at separate locations (invalid trials). A typical pattern of results is that behavioral performance is better for the valid than for the invalid trials. This result is attributed to the fact that the cue orient participants' attention toward the cued location.

What is remarkable is that even when the cue does not provide any information regarding the target stimulus, such that there should be no incentive to process the cue stimulus, behavioral performance differs across the cue types. For example, imagine that there are four potential target locations, and the probability that the cued location and the target location match is 25%. In other words, the proportion of valid trial is 25%, while the remaining 75% of the trials are invalid ones. In this case, there is no correlation between the cue location and target location, rendering the cue non-informative of the target location. Despite this, participants' attention has been found to be oriented toward the cued location. This finding led to the claim that a salient, non-informative cue captures attention in an involuntary manner. This involuntary capture of attention is also claimed to be automatic and effortless, which is independent of top-down attentional control.

However, a recent study provided evidence challenging the automaticity of involuntary attention. Specifically, in a study by Du and Abrams (2009), the attentional blink paradigm, in which participants are required to detect target stimuli in a rapid serial visual presentation (RSVP) of distractors, and the spatial cuing paradigms were used in combination. Participants identified a target stimulus (green letter) in the RSVP of distractors (gray letters) and encoded the target letter into working memory for later report. Following the RSVP, a probe letter was presented in periphery. Participants were also required to report the identity of the probe. Importantly, the stimulus onset asynchrony (SOA) between the letter target and the probe was manipulated (300, 400, & 800 ms). Another important manipulation was that a salient cue, which was non-informative of the probe location, was presented 100 ms before the probe onset. The results showed that the effect of non-informative cue on probe identification was found only when the SOA was long (400 ms, 800 ms). Based upon this result, they suggested that attentional capture by non-informative cue is affected by whether the attentional resources are available or not. Similar findings were also

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reported by Visser (2011).

In contrast to the above study, Ghorashi and colleagues reported a series of findings showing that the AB affected spatial cuing effect (Ghorashi, Enns, Spalek, & Di Lollo, 2009; Ghorashi, Spalek, Enns, & Di Lollo, 2009). Notably, those studies employed endogenous cuing paradigm. Hence, these studies do not directly contradict to the Du and Abrams study. However, in a study, Ghorashi and colleagues showed that the effect of the non-informative cue was independent of the availability of attentional resources (SMS Ghorashi, Di Lollo, & Klein, 2007; Ghorashi, Enns, Klein, & Di Lollo, 2010). In the study by Ghorashi et al. (2010), similarly with the study by Du and Abrams (2009), participants identified a letter (First target, T1) embedded in the RSVP. They also searched for a tilted T (Second target, T2) among rotated Ls and reported the orientation of the T. The non-informative cue of the T2 location was presented 90, 180, or 540 ms after the onset of T1 presentation. The results showed that the non-informative cue did affect the performance of the second target, regardless of the T1-cue intervals.

How can one reconcile these conflicting results? To explain this discrepancy, we suggest to consider that attention is a multifaceted mechanism, exerting various effects. First, attention enhances the perception of a single stimulus by enhancing the quality of perceptual representation of the stimulus presented at the attended location (Cameron, Tai, & Carrasco, 2002; Carrasco, Penpeci-Talgar, & Eckstein, 2000; Herrmann, Montaser-Kouhsari, Carrasco, & Heeger, 2010; Ling & Carrasco, 2006; Pestilli & Carrasco, 2005; Pestilli, Viera, & Carrasco, 2007; White, Lunau, & Carrasco, 2014). This is done via reducing external noise imposed on the stimulus (Dosher & Lu, 2000), or via enhancing weak sensory signal in noise-free condition (signal enhancement, see Carrasco et al., 2000). Attention also affects the perception of a stimulus via resolution of stimulus-driven competition. When multiple stimuli are presented, they compete to be represented in the visual system because perceptual capacity is limited (Desimone & Duncan, 1995; Duncan, 1998). The competition can be resolved by attention, such that perceptual processing is biased toward the attended stimulus (Beck & Kastner, 2005).

Second, attention can affect behavioral performance without changing perception. In the presence of multiple items briefly presented, people are uncertain about the location of the target stimulus. Many previous studies showed that when attention is directed to the target location by a spatial cue, the target performance is enhanced because the attentional cue reduces the target location uncertainty without changing the quality of perceptual representation of the target (Gould, Wolfgang, & Smith, 2007; Prinzmetal, Ha, & Khani, 2010; Prinzmetal, McCool, & Park, 2005; Prinzmetal, Park, & Garrett, 2005; Shiu & Pashler, 1994).

Given the above, the attentional effect found in the study by Ghorashi et al. (2010) might have arisen because the attentional cue had reduced the target location uncertainty. In their study, the target location might have been uncertain due to the presence of multiple distractors. By contrast, in the study by Du and Abrams (2009), the attentional effect might have been primarily driven by perceptual enhancement because the probe stimulus was presented by itself, minimizing the location uncertainty.

Based upon these, we suggest that the availability of top-down attentional resource affects the perceptual effect of involuntary attention when a single target stimulus is presented (Du & Abrams, 2009). This is because to enhance the perception of a single stimulus, attentional resource should be allocated to the target (Prinzmetal, McCool, & Park, 2005). This attentional resource is also recruited for T1 processing (Jolicœur, Sessa, Dell'Acqua, & Robitaille, 2006; Robitaille, Jolicœur, Dell'Acqua, & Sessa, 2007). In contrast to this, when a target is surrounded by multiple distractors, evoking target location uncertainty, the effect of involuntary attention on the target identification is independent of top-down attentional resources (Ghorashi et al., 2010). Contrary to perceptual enhancement, the reduction of location uncertainty might take place without deploying attentional resource recruited for T1 processing (Prinzmetal, McCool, & Park, 2005).

Another important issue to be addressed is how T1 processing affects the process of resolving competition by involuntary attention. The presentation of multiple stimuli evokes both the target location uncertainty and stimulus-driven competition. To clarify whether the AB interacts with the attentional process for resolving competition or not, one should measure the attentional effect when multiple stimuli are simultaneously presented, but should eliminate target location uncertainty.

The present study aimed to resolve the controversy about whether the availability of attentional resource affects the effect of involuntary attention. We hypothesized that the dependence of involuntary attention on the availability of attentional resource interacts with the presence/absence of distractor interference and target location uncertainty. Specifically, the perceptual effect of involuntary attention on a stimulus presented by itself should be affected by the availability of top-down attentional resources. By contrast, when the target stimulus is accompanied by multiple distractors, evoking target location uncertainty and stimulus-driven competition, the effect of involuntary attention should be independent of whether top-down attentional resources are depleted or not.

To test these hypotheses, we employed the attentional blink (AB) and the spatial cuing paradigms. In the experiments, participants performed a dual-task consisting of the identification of a letter (first target, T1) and a Gabor grating (second target, T2). Specifically, after T1 was presented, a salient, but task-irrelevant cue was presented, immediately followed by T2 presentation. To test the interaction between the availability of top-down attentional resource for T1 and the effect of the attentional cue preceding T2, the SOA between T1 and cue presentations was manipulated. While several previous studies also addressed a similar issue using paradigms combining the attentional blink and attentional cuing (Ghorashi, Enns, et al., 2009; Ghorashi, Spalek, et al., 2009; Nieuwenstein, Chun, van der Lubbe, & Hooge, 2005; Olivers, 2004), they employed either an endogenous cue or temporal cue.

We first tested whether the perceptual effect of the attentional cue on a single stimulus depends on the T1-cue SOA (Experiment 1). Importantly, we omitted the backward mask that follows the T2. This is to investigate whether the AB affects the process of signal enhancement by spatial attention in a noise-free condition. Second, we tested whether the T1-cue SOA influences the attentional effect when T2 is accompanied by multiple distractors, evoking the target location uncertainty (Experiment 2). In the final experiment, we investigated how T1-cue SOA affects the attentional effect when multiple distractors were presented with T2, but, importantly, the T2 location uncertainty was eliminated by providing a response cue denoting the target location (Experiment 3). This experiment allows us to test whether the resolution of stimulus-driven competition by attention depends on top-down attentional resources or not.

1. Experiment 1

Experiment 1 investigated whether the perceptual effect of involuntary attention on a single stimulus is affected by the attentional blink. To test this, we combined the attentional blink paradigm and the spatial cuing paradigm. While identifying and encoding a letter target, which was embedded in a rapid serial visual presentation (RSVP) of digit distractors, into working memory, participants judged the orientation of a grating target presented in periphery. Importantly, a salient peripheral cue, presumed to involuntarily capture attention, preceded the grating. We examined how the concurrent load of the target letter processing affects the effect of the cue in periphery by manipulating the stimulus-onset asynchrony (SOA) between the letter onset and the cue onset.