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Contingent capture can occur at specific feature values: Behavioral and electrophysiological evidence

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ABSTRACT

The notion that attentional top–down control can be tuned to a stimulus feature is widely accepted. Although previous studies suggested that the stimulus-driven attentional capture could be contingent on top–down attentional control settings, it was uncertain whether contingent capture can occur at a specific feature value. Three experiments were conducted to address this issue using both behavioral and ERPs measures. Participants were required to respond to one color singleton in the search display (target) but refrain from responding to the search display containing another color singleton (nontarget). When target and nontarget belonged to different color categories (Experiment 1), only the target-color cue and within category irrelevant-color cue elicited the significant cue validity effect (i.e. RTs were shorter when the target was presented at the same location as the preceding cue rather than at a different location); they also lead to a robust N2pc effect, indicative of attention-capture. In addition, these two cue types had similar attention-capturing capacity. However, when target and nontarget belonged to the same color category (Experiments 2 and 3), only the target-color cue elicited the significant cue validity effect and the robust N2pc effect. The same within category irrelevant-color cue no longer elicited the cue validity effect, and the N2pc effect was also attenuated. Present findings suggest that contingent capture can occur at a specific feature value.

1. Introduction

Over the past two decades, there have been heated debates concerning the extent to which attentional capture is controlled either by certain stimulus properties in an involuntary, bottom-up fashion or by behavioral goals of the observer in a voluntary, top–down fashion. It has been argued that perceptually salient stimuli can automatically capture attention irrespective of the observer's intentions or goals. For instance, Theeuwes (1992; see also 1991, 1994), using the *additional singleton paradigm* – in which participants searched for a singleton target among several displayed items (e.g., a green circle among all green diamonds), found that the presence of a task-irrelevant singleton (e.g., a red diamond) among displayed items resulted in slowed responses. He therefore suggested the "pure-capture hypothesis", which stated that attentional capture is determined by bottom-up salience of the stimulus, irrespective of whether or not the observer is actually looking for it. However, Folk et al. (1992), using a *spatial cuing paradigm* – in which the target display was preceded by a cue display, found that the spatially uninformative color singleton cue produced a cue validity effect, i.e. reaction times (RTs) were faster for targets at cued versus uncued locations (evidence of attentional capture), in blocks where target itself was also a color singleton but not an onset singleton. Similarly, the spatially nonpredictive onset singleton cue produced the cue validity effect in blocks where target itself was also the onset singleton but not the color singleton. On the basis of such findings, they proposed the "contingent capture hypothesis", which stated that salient stimuli automatically capture an observer's attention only when their properties match the top–down control settings. The classic findings of Folk et al. (1992) have been replicated many times in subsequent experiments (Al-Aidroos et al., 2010; Folk and Remington, 1999; Folk et al., 1994; Gibson and Amelio, 2000; Gibson and Kelsey, 1998; Lien et al., 2010a).

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Bacon and Egeth (1994) offered an explanation for the controversy between the pure-capture hypothesis and the contingent-capture hypothesis. They argued that specific search mode adopted by the observer is what determines whether or not salient stimuli captured attention. Specifically, in the Theeuwes (1992) study, the target was a singleton in a given dimension (e.g., a circle among diamonds), and participants might choose to adopt the singleton-detection mode, in which singletons in all dimensions would capture attention. Thus, the irrelevant singleton increased response time to the target. While, when participants were required to search for a specific feature that was not a singleton, they were forced to use the feature search mode. As a consequence, the presence of the same irrelevant singleton no longer captured attention and affected search performance. In support of this claim, Bacon and Egeth (1994), using the additional singleton paradigm, showed that interference from an irrelevant color singleton was observed when the target was a shape singleton (participants adopted singleton-detection mode), replicating Theeuwes's finding. In contrast, no such distracting effect of the very same irrelevant color singleton was found when shape targets were not unique in the shape dimension (participants were forced to adopt feature-search mode).

Combing behavioral and electrophysiological approach, a recent study by Eimer and Kiss (2010) provided compelling evidence for the existence of two search modes. They found that when two color singletons were defined as targets (Experiment 1, e.g., search for red and green singleton targets), both the target-color singleton cue and the irrelevant-color singleton cue elicited cue validity effects and an N2pc (short for N2-posterior-contralateral) effect (indicating attentional capture). However, when participants were required to refrain from responding to one type of color singletons (Experiment 2, e.g., ignore green singletons while attending to red targets), the cue validity effect was only observed for target-color cue condition (e.g., red color singleton cue); no cue validity effects were seen for the nontarget-color cue condition (e.g., green color singleton cue) and the irrelevant-color cue condition. These findings indicated that participants adopted the singleton search mode in Experiment 1 and the feature-specific search mode in Experiment 2.

The study by Eimer and Kiss (2010) and also others (e.g., Eimer and Kiss, 2008; Eimer et al., 2009; Lamy and Egeth, 2003; Lien et al., 2010b) showed that attentional capture depends critically on the match between the stimulus feature and participants' top–down attentional set. However, it is not clear how precise the match needs to be for attentional capture to take place. For example, if the target-defining feature was "redness", could all shades of "redness" cue that matched the target on a broad color category capture attention or would only the cue with one particular level of "redness" (one which exactly matched the target's shade) capture attention? More importantly, under what conditions would these effects take place?

A study by Ansorge and Heumann (2003), also using the spatial cuing paradigm, showed that when participants were instructed to search for one abrupt onset target with specific color (e.g., green), the cue which had a different feature value but the same color category as the target (e.g., bluish green) triggered a stronger cuing effect than the cue from a different color category than that of the target (e.g., yellowish red). Based on these results we might argue that contingent capture could occur at a category level. But it is still unclear whether contingent capture can occur at a specific feature value.

It has been suggested by Navalpakkam and Itti (2006), using a visual search paradigm, that attentional top–down task sets can be finely tuned to the specific feature value. They instructed participants to search for a known single interval target among three intervals (LOW, MID, and HIGH intervals) distracters. The results showed that participants could selectively saccade to relevant interval in contrast to irrelevant intervals.

A recent study by Kiss and Eimer (2011) examined contingent capture that occurs at size dimension. They found that small or large size singleton cues triggered cue validity effects and N2pc components only when these cues matched the current target defining feature. Specifically, they found that when participants' task was to respond to small targets, small cues elicited the N2pc and behavioral spatial cue validity effects, but not for large cues; while, when participants were instructed to search for large targets, the N2pc and behavioral spatial cue validity effects were observed for large cues, but not for small cues. In their study, search displays contained six gray bars and the target bar was either smaller or larger than the other five bars, while cue displays contained six gray items composed of four dots and one item was either smaller or larger than the others. Because shapes of stimulus items in the cue and search displays were not the same, the size of stimulus items in the cue and search displays could not be easily compared. Instead, the size information of stimulus items in cue and search displays was available in relative terms (in contrast to other stimulus elements in the same display). Therefore, it is reasonable to argue that participants could categorically discriminate relative small vs. large, rather than pay attention to the absolute value of the size. Thus, in their study, singleton items in cue displays and target displays could match on the category, namely relatively small or large size category, rather than on the exact value of size dimension. Based on their findings, strictly speaking, it is safer to conclude that contingent capture can occur at a broad size category rather than feature value.

In summary, whether contingent capture can occur at the specific feature value remains inconclusive. The present study was designed to shed additional light on this issue, by focusing on color attribute of the stimulus where both the color category and shade of color could be part of the attentional task set. It has been well documented that color perception exhibits characteristics of categorical perception (Kay and Kempton, 1984). This has been demonstrated by faster or more accurate performance on between-category discrimination (e.g. comparing green to blue) than on within-category discrimination (e.g. comparing two different shades of green). In the context of color, the hierarchy of a category (e.g., green) and a specific feature value within a category (e.g., a shade of green) has already been established. Moreover, by having the color category and/or the shade of color match exactly between the cue and target/nontarget, our stimulus allows a direct comparison of the absolute value of the color feature between cue and search displays. Thus, this approach offered a direct test of whether, and in what condition, attentional capture can be extended from feature category to specific value of the features.

We employed a similar spatial cuing paradigm used by Eimer and Kiss (2010, Experiment 2). Similar to Eimer and Kiss (2010), we also combined behavioral and electrophysiological measures of attentional capture. We expected to obtain the N2pc component in the ERP waveform. The N2pc is an ERP component characterized by an increased negativity over posterior scalp contralateral to an attended stimulus observed between 180 and 300 ms after display onset, and is assumed to reflect the allocation of attention to an object in a visual display (Eimer, 1996; Hickey et al., 2006; Jolicoeur et al., 2006; Luck and Hillyard, 1994; Mazza et al., 2007).

For cue displays, we employed four different types of color singleton cue. Three (target-color cue, irrelevant-color cue, nontarget-color cue) of them had been used in Experiment 2 in Eimer and Kiss (2010). The irrelevant-color cue in our study was a cross-category irrelevant-color cue. The fourth one was a within-category irrelevant-color cue with the same color category (but a different RGB value) as that of the target.

In addition to cue types, we also manipulated target and non-target stimulus properties. In Experiment 1, color categories